REMARKS

Claim Rejections – 35 USC 103

Claims 1-3, 5-6, 8, 10-12, 14-15 and 17 are rejected under 35 U.S.C. 103(a) as being unpatentable over Awater et al. (US 2005/0152317) in view of Gummadi et al. (US 7,136,436) further in view of Chow et al. (US 2005/0276340).

Claims 4, 7, 13 and 16 are rejected under 35 U.S.C. 103(a) as being unpatentable over Awater et al. (US 2005/0152317) in view of Gummadi et al. (US 7,136,436) further in view of Chow et al. (US 2005/0276340) as applied to claims 1, 3, 6, 10-12 and 15 above and further in view of Narasimhan (US 7,218,691).

Claims 9 and 18 are rejected under 35 U.S.C. 103(a) as being unpatentable over Awater et al. (US 2005/0152317) in view of Gummadi et al. (US 7,136,436) further in view of Chow et al. (US 2005/0276340) as applied to claims 1 and 10 above, and further in view of Mui (US 6,690,739).

Response:

Examiner has cited the Chow reference (US 2005/0276340) for rejecting the pending claims 1-16 in view of other cited references under 35 U.S.C. 103(a). However, the conception of applicants' invention was established at least as early as the date a written description of the invention disclosure possessed and completed by the applicants was delivered to the undersigned representative of the applicants, which was prior to the effective filing date of the Chow reference on which the rejection is based; in addition, the undersigned representative of applicants and co-working assistants under his direct supervision, including a draft person, an editor, an electronic filing system operator, etc., were diligent in preparing the instant patent application based on applicants' written description of the invention disclosure and diligent in filing the finalized draft of the instant patent application reviewed and confirmed by the applicants. Therefore, withdrawal of the rejections made to the pending claims 1-26 is respectfully requested as a

declaration under 37 CFR 1.131 has been submitted to antedate the cited Chow reference qualified as prior art under 35 U.S.C. 103(a) via 35 U.S.C. 102(e).

A separate signed declaration under 37 C.F.R. 1.131 is attached to this reply to formally show facts directed to establishing conception of the invention prior to the effective date of the reference coupled with due diligence from prior to said date to the filing of the instant patent application.

Sincerely yours,

Winston Hsu Date: 03/18/2008

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Note: Please leave a message in my voice mail if you need to talk to me. (The time in D.C. is 12 hours behind the Taiwan time, i.e. 9 AM in D.C. = 9 PM in Taiwan.)

Exhibit A

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主旨： 瑞昱新案委託/93A-023
日期： 2004年3月19日 上午 11:32:40
附件： 93A-023.doc

千惠

委託　貴事務所新案：『93A-023 』(參附件檔)
一、今將專利事務委託單傳真給您，請直接在委託單上簽名蓋章，回傳予我，方完成委託程序。
二、請回覆　貴事所案件編號以及安排工程師近期與我會談之時間。
如何任何問題歡迎與我聯繫 Morrie ext:5628。

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Exhibit B

Frequency domain ISI / ICSI detection in OFDM Based System

1.Prior Art

一般 OFDM 系統多規劃有 guard interval，用以避免 Inter-symbol interference (ISI)的產生。

然而訊號傳遞的 channel 情況會因應用不同而有很多情況，所以在現實 OFDM 接收機處理時，仍有機會因為 FFT boundary 選取不恰當，造成 ISI 以及 Inter-carrier interference；一般之先前技術多從 FFT 後相位會因為 time domain 的 circular shift 而有 freq. domain linear phase shift 直接估出 boundary 應移動多少；或是由 channel 的 impulse response 上尋找能量較大的位置，同樣直接估判出 boundary 應移動多少。

但由於上述這些類型的作法，恐會面臨估測不準時，導致無法收斂或是接收失敗。故倘若能適當估測出這些 Interference 的產生情況，可提供接收機針對 Interference 的來源方向去做適當的小幅移動 boundary，以得到較穩定的接收效果。

2.基本原理

為了適當地判斷 OFDM 訊號是否遭受 ISI 或是 ICI，可利用 FFT output 針對三種情況估測得 Interference 的發生情況。

I. ISI-pilot carrier (different in every OFDM symbol)

利用已知的 K 根 pilot carrier，同時 pilot carrier 的值會隨著不同 symbol 而改變。由於每個 sub-carrier 的 ISI 多由前後 symbol 的相同 sub-carrier 所貢獻。故可利用已知的 pilot，估測得目前 symbol 與前、後 symbol 的 correlation 為：

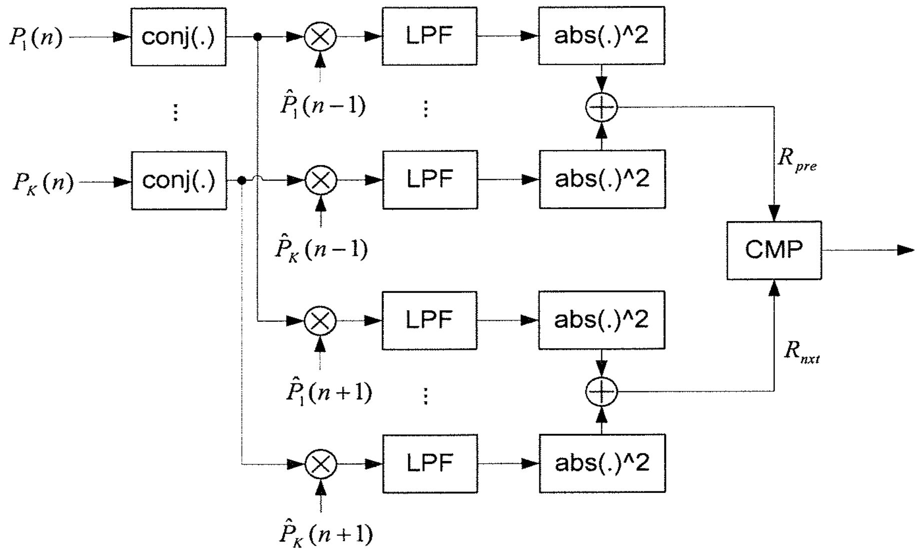
$$R_{pre} = \sum_{k=1}^{K} abs(E[\hat{P}_k(n-1) \cdot P_k(n)^*])^2$$

$$R_{nxt} = \sum_{k=1}^{K} abs(E[\hat{P}_k(n+1) \cdot P_k(n)^*])^2$$

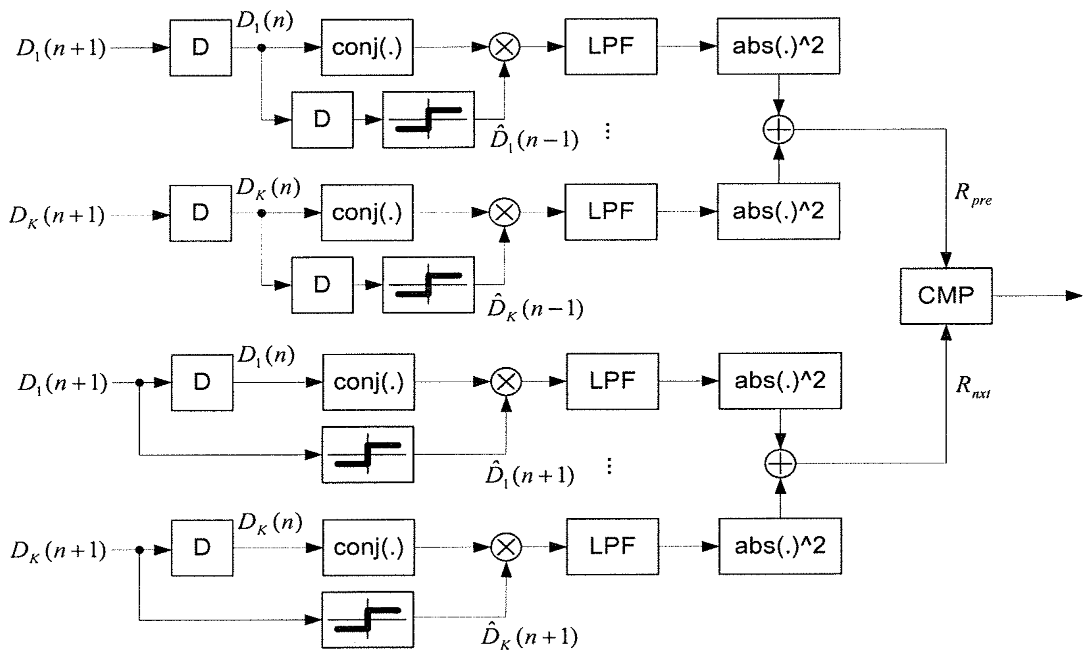
其中， $P_k(n)$ 為接收到 n-th symbol, k-th sub-carrier 的值； $\hat{P}_k(n)$ 為已知 n-th symbol, k-th sub-carrier 的值。

$E[\hat{P}_k(n-1) \cdot P_k(n)^*]$ 可由 moving average 或是簡單的 LPF 得到（如圖一所示）。

再根據比較器的結果得到，當 Rpre>Rnxt，則表示 ISI 來自前一個 symbol；當 Rpre<Rnxt，則表示 ISI 來自下一個 symbol。



圖一



圖二

II. ISI-data signal (decision directed)

倘若 pilot 不會隨不同 symbol 改變，則可採用 decision-directed 的方式，挑選 K 根 sub-carrier，可估測得目前 symbol 與前、後 symbol 的 correlation 為：

$$R_{pre} = \sum_{k=1}^{K} abs(E[\hat{D}_k(n-1) \cdot D_k(n)^*])^2$$

$$R_{nxt} = \sum_{k=1}^{K} abs(E[\hat{D}_k(n+1) \cdot D_k(n)^*])^2$$

其中，$D_k(n)$ 為接收到 n-th symbol, k-th sub-carrier 的值；$\hat{D}_k(n)$ 為 decision 後 n-th symbol, k-th sub-carrier 的值。

同樣根據比較器的結果得到，當 Rpre>Rnxt，則表示 ISI 來自前一個 symbol；當 Rpre<Rnxt，則表示 ISI 來自下一個 symbol。（如圖二所示）

III. ICSI-data signal(decision directed)

另外，若考量由相鄰 sub-carrier 所貢獻的 ICI，同樣利用 decision directed 的方式，挑選 K 根不相鄰的 sub-carrier，假設個別的 freq. domain index 為 x_1~x_k，估測得目前 symbol 與前、後 symbol 的 correlation 為：

$$R_{pre} = \sum_{k=1}^{K} \left(abs(E[\hat{D}_{x_k-1}(n-1) \cdot D_{x_k}(n)^*])^2 + abs(E[\hat{D}_{x_k+1}(n-1) \cdot D_{x_k}(n)^*])^2 \right)$$

$$R_{nxt} = \sum_{k=1}^{K} \left(abs(E[\hat{D}_{x_k-1}(n+1) \cdot D_{x_k}(n)^*])^2 + abs(E[\hat{D}_{x_k+1}(n+1) \cdot D_{x_k}(n)^*])^2 \right)$$

其中，$D_{x_k}(n)$ 為接收到 n-th symbol, x_k-th sub-carrier 的值；$\hat{D}_{x_k}(n)$ 為 decision 後 n-th symbol, x_k-th sub-carrier 的值。

同樣根據比較器的結果得到，當 Rpre>Rnxt，則表示 ISI 來自前一個 symbol；當 Rpre<Rnxt，則表示 ISI 來自下一個 symbol。

3.優缺點

正確的估測 ISI/ICSI 的來源方向，可提供穩定的調整 FFT Boundary，進而可進行 boundary tracking。

適當地選擇 average 的 LPF，與所觀察的 sub-carrier，可提升估測 interference 來源方向的正確性。

針對 pilot or data subcarrier，皆可利用來估測 interference。

寄件者： Candice Kao(高千惠)
收件者： CUST.陳美齡;
主旨： RE: 3/25 Patent Application Discussion Meeting
日期： 2004年3月22日 下午 12:00:21
附件： REA-P0087,90,91-T,U,C,J.doc
REA-P0088,89-T,U,C.doc

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本所承辦工程師為Paul/ Carlos帶Mark, Ivy, Calvin
如果您有任何問題, 煩請不吝與我聯絡, 謝謝!
Best regards,

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-----Original Message-----
From: CUST.陳美齡
Sent: Friday, March 19, 2004 5:15 PM
To: Candice Kao(高千惠)
Subject: 3/25 Patent Application Discussion Meeting

Dear Candice,
The agenda for 3/25 Patent application discussion meeting as following.

Morrie / 陳美齡
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Dear All
Please attend on time! Thank you.
If you are not available to attend the meeting please contact me.

--Morrie x5628

3/25 Patent Appication Discussion Meeting

Room: 5-2

Time	Num.	Inventor(s)	Ext	Invention Title	IP Engineer(s)
10:00~11:00	93A-026	顏光裕	3884	A new decording strategy for DVD	Colin/Matt/Weber
		郭協星	3886		
11:00~12:00	93A-027	黃仙名	5577	PCI多重功能元件共用相同驅動程式之界面與方法	
		黃上已	5523		
		周欣儀	3531		
13:00-14:00	93A-023	卓俊銘	5509	Frequency domain ISI / ICSI detection in OFDM Based System	Colin/Matt/Weber
		顏光裕	3884		
14:00-15:00	93A-024	趙柏偉	3340	Faise color suppression	
15:00-16:00	93A-025	趙柏偉	3340	Block search and weight blending De-interlacing	

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Exhibit D

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主旨： 請查收93A-023(REA-P0087-USA)初稿及簽名文件
日期： 2004年5月31日 下午 03:32:51
附件： REAP0087USA0.DOC
rea087assign-usa.TIFF
REA087dec-usa.TIFF

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如果您有任何問題, 煩請不吝與我聯絡, 謝謝!
Best regards,

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CUST#93A-023
NPO#REA-P0087-USA:0/初稿/金若芸

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【修正意見：　】

Title

METHOD AND APPARATUS OF DETECTING ISI/ICSI IN AN OFDM SYSTEM FOR CORRECTLY TUNING A BOUNDARY UTILIZED BY THE OFDM SYSTEM

Background of Invention

1. Field of the Invention

The invention relates to an apparatus and a method of tuning a boundary of an OFDM system, and more particularly, to a method and an apparatus of detecting ISI/ICSI in an OFDM system for correctly tuning a boundary utilized by the OFDM system.

2. Description of the Prior Art

Generally speaking, most OFDM transceivers suffer from well-known problems of inter-symbol interference (ISI) and inter-carrier interference (ICI). Therefore, some slices in a packet of the OFDM transceiver are reserved for a plurality of guard intervals (GI) to reduce the influence of the ISI and the ICI. Please refer to Fig.1, which is a schematic diagram of a prior art OFDM receiver 10. As shown in Fig.1, the OFDM receiver 10 comprises a boundary detector 18 for detecting a boundary of symbols, a GI remover 15 for removing a plurality of GIs in each symbol according to the boundary and outputting the data S1, a fast fourier transformer (FFT) 17 for demodulating the data S1 transmitted via different sub-carriers using each symbol to output the demodulated data S2, and a timing controller 19 for providing timing to the GI remover 15 to triggering the removal of GIs. However, the detected boundary may not be reliable owing to the influence of multi-path and other factors.

One prior art applied to solve this problem detects the phase shift of the demodulated data S_2, estimates the time shift of the transmitted data S_1 caused by the time shift of the detected boundary according to the FFT theorem, and then shifts the timing of the boundary for a determined distance according to the time shift. That is,

the boundary is shifted to a correct position within the packet. Another prior art disclosed estimates the time shift of the boundary through the channel impulse response, and then shifts the timing of the boundary for a determined distance according to the time shift.

Unfortunately, both of those two prior art techniques may cause divergence, which seriously damages the reliability of the OFDM receiver 10. It is because those two prior art techniques adjust the boundary too fast by shifting the boundary by a determined distance. The boundary detector 18 may make a mistake in detecting the required boundary. In other words, an erroneous boundary is detected by the boundary detector 18 when the surrounding environment is full of noise. Therefore, it's difficult to tune the boundary back to a correct position according to the erroneously detected boundary. As a result, the OFDM receiver 10 may malfunction. How to correctly tune the boundary is very important for the OFDM receiver 10 in order to extract the wanted data from the received packet.

Summary of Invention

It is therefore one of objectives of the claimed invention to provide a method and an apparatus of detecting ISI/ICSI in an OFDM system for correctly tuning a boundary utilized by the OFDM system to solve the above-mentioned problem.

According to an embodiment of the claimed invention, an ISI detector is disclosed. The ISI detector comprises a first correlator for computing a first correlation value according to a pilot data transmitted using a current symbol via a pilot sub-carrier and a first comparison data corresponding to a pilot data transmitted using a previous symbol via the pilot sub-carrier; a second correlator for computing a second correlation value according to the pilot data transmitted using the current symbol and a second comparison data corresponding to a pilot data transmitted using the next symbol via the pilot sub-carrier; a comparator connected to the first correlator and the second correlator for generating a control signal; and a timing controller

connected to the comparator for shifting the timing of a boundary of the OFDM system according to the control signal.

According to an embodiment of the claimed invention, an ICSI detector is disclosed. The ICSI detector comprises a first correlator for computing a first correlation value according to a first data transmitted using a current symbol via a first sub-carrier and a second data transmitted using a previous symbol via a second sub-carrier ; a second correlator for computing a next correlation value according to the first data transmitted using the current symbol and a third data transmitted using a next symbol by the second sub-carrier ; a comparator connected to the first correlator and the second correlator for generating a control signal; and a timing controller connected to the comparator for shifting the timing of a boundary of the OFDM system according to the control signal.

Brief Description of Drawings

Fig.1 is a schematic diagram of a prior art OFDM receiver.

Fig.2 is a schematic diagram of an ISI detector according to one embodiment of the present invention.

Fig.3 is a schematic diagram of an ISI detector according to another embodiment of the present invention.

Fig.4 is a schematic diagram of an ICSI detector according to an embodiment of the present invention.

Detailed Description

In order to solve the problem mentioned above, the primary objective of the invention provides an ISI/ICSI detector and a related method for detecting the source where the interference is introduced. Then, the boundary is shifted away from the source by a very small distance repeatedly, which reduces the influence of ISI/ICSI gradually.

Please refer to Fig.2, which is a schematic diagram of an ISI detector 20 according to one embodiment of the present invention. As shown in Fig.2, the ISI detector 20 is connected to a timing controller 62, and the ISI detector 20 comprises two correlators 21, 41 and a comparator 60. The correlators 21, 41 are used for respectively generating a correlation value R_{pre} and a correlation value R_{nxt}. The correlation value R_{pre} stands for the magnitude of the ISI generated from a previous symbol, and the correlation value R_{nxt} stands for the magnitude of the ISI generated from a next symbol. The comparator 60 is used to compare the correlation value R_{pre} with the correlation value R_{nxt} and generate a control signal Sc according to the comparison result. The timing controller 62 has the same functionality as that of the timing controller 19 shown in Fig.1. That is, the timing controller 62 in this preferred embodiment is used to control the timing of a boundary of an OFDM system according to the control signal Sc.

As shown in Fig.2, the correlator 21 comprises a plurality of conjugating units 22, 32; a plurality of multipliers 24, 34; a plurality of low-pass filters 25, 35; a plurality of absolute value calculating units 26, 36; and a summation unit 28. The conjugating units 22, 32 are used for generating conjugated pilot data $P_1(n)^*$, $P_k(n)^*$ by conjugating corresponding pilot data $P_1(n)$, $P_k(n)$ that was transmitted using a current symbol. The multipliers 24, 34 are used for respectively generating product values by multiplying those conjugated pilot data $P_1(n)^*$, $P_k(n)^*$ with a corresponding comparison data $\hat{P}_1(n-1)$, $\hat{P}_k(n-1)$ that was transmitted using a previous symbol. The low-pass filters 25, 35 are used for averaging the product values outputted from these multipliers 24, 34, respectively. The absolute value calculating units 26, 36 are used for generating absolute values of the average values corresponding to the product values. The summation unit 28 is used for generating a correlation value R_{pre} by

summing these absolute values.

Similarly, the correlator 41 comprises a plurality of conjugating units 42, 52; a plurality of multipliers 44, 54; a plurality of low-pass filters 45, 55; a plurality of absolute value calculating units 46, 56; and a summation unit 48. The conjugating units 42, 52 are used for generating conjugated pilot data $P_1(n)^*$, $P_k(n)^*$ by conjugating corresponding pilot data $P_1(n)$, $P_k(n)$ that was transmitted using a current symbol. The multipliers 44, 54 are used for respectively generating product values by multiplying those conjugated pilot data $P_1(n)^*$, $P_k(n)^*$ with a corresponding comparison data $\hat{P}_1(n+1)$, $\hat{P}_k(n+1)$ that was transmitted using a next symbol. The low-pass filters 45, 55 are used for averaging the product values outputted from these multipliers 44, 54, respectively. The absolute value calculating units 46, 56 are used for generating absolute values of the average values corresponding to the product values outputted from these multipliers 44, 54. The summation unit 48 is used for generating a correlation value R_{nxt} by summing these absolute values.

According to the well-known theorem of correlation, the following Equations (1) and (2) are used to better explain operations of the correlators 21, 41.

$$R_{pre} = \sum_{k=1}^{K} abs(E[\hat{P}_k(n-1) \cdot P_k(n)^*]) \qquad \text{Equation (1)}$$

$$R_{nxt} = \sum_{k=1}^{K} abs(E[\hat{P}_k(n+1) \cdot P_k(n)^*]) \qquad \text{Equation (2)}$$

$P_k(n)^*$ denotes the conjugated pilot data transmitted using an n^{th} symbol via the a k^{th} sub-carrier, $\hat{P}_k(n-1)$ denotes the comparison data transmitted using an $(n-1)^{th}$ symbol via a k^{th} sub-carrier, and $\hat{P}_k(n+1)$ denotes another comparison data

transmitted using an $(n+1)^{th}$ symbol via a k^{th} sub-carrier. Please note that the more sub-carriers that are considered, the more reliable result will be generated.

In some OFDM systems, the pilot data transmitted via the same pilot sub-carrier using different symbols have known but different predetermined values. Therefore, $\hat{P}_k(n-1)$ and $\hat{P}_k(n+1)$ in the above embodiment denote those known predetermined values of pilot data. If the correlation value R_{pre} is greater than the correlation value R_{nxt}, it means that the interference is introduced from using the previous symbol; this is due to the fact that the timing of the actual boundary leads that of the ideal boundary. Therefore, the comparator 60 outputs the control signal Sc to the timing controller 62 for delaying the timing of the actual boundary. On the otherhand, if the correlation value R_{pre} is less than the correlation value R_{nxt}, it means that the interference is introduced from using the following symbol; this is due to the fact that the timing of the actual boundary lags behind that of the ideal boundary. Therefore, the comparator 60 outputs the control signal Sc to the timing controller 62 for advancing the timing of the actual boundary. As a result, the ISI effect is alleviated.

Please refer to Fig.3, which is a schematic diagram of an ISI detector 80 according to another embodiment of the present invention. As show in Fig.3, the ISI detector 80 comprises two correlators 90, 110 and a comparator 120. The correlators 90, 110 are used for generating correlation values R_{pre} and R_{nxt}, respectively. The comparator 120 compares the correlation value R_{pre} with the correlation value R_{nxt} for outputting a control signal Sc to control the timing controller 129.

In this preferred embodiment, the correlator 90 has a plurality of delay circuits

91a, 91b, 101a, 101b; a plurality of conjugating units 92, 102; a plurality of multipliers 93, 103; a plurality of equalizers 94, 104; a plurality of low-pass filters 95, 105; a plurality of absolute value calculating units 96, 106; and a summation unit 98. Concerning the other correlator 110, it has a plurality of delay circuits 111, 121; a plurality of conjugating units 112, 122; a plurality of multipliers 113, 123; a plurality of equalizers 114, 124; a plurality of low-pass filters 115, 125; a plurality of absolute value calculating units 116, 126; and a summation unit 128. Please note that the components shown in Figs.2 and 3 that have the same name have identical functionality and operation. The related description, therefore, is not repeated for simplicity.

The major difference between the correlators 90, 110 shown in Fig.3 and the correlators 21, 41 shown in Fig.2 is the configuration of the delay circuits 91a, 91b, 101a, 101b and the equalizers 94, 104, 114, 124.

For an OFDM system having pilot data transmitted via the same pilot sub-carrier using different symbols corresponding to an identical value, the ISI detector 80 is utilized. As shown in Fig.3, the comparison data $\hat{Q}_1(n-1)$ and $\hat{Q}_k(n-1)$ are generated by equalizing the pilot data $Q_1(n-1)$ and $Q_k(n-1)$ through the corresponding equalizers 94 and 104, wherein the pilot data $Q_1(n-1)$ and $Q_k(n-1)$ are delayed and transmitted to the equalizers 94 and 104 by the delay circuits 91a, 91b, 101a, 101b. Regarding the comparison data $\hat{Q}_1(n+1)$ and $\hat{Q}_k(n+1)$, they are generated by directly equalizing the pilot data $Q_1(n+1)$ and $Q_k(n+1)$ with the corresponding equalizers 114 and 124.

With the circuit configuration shown in Fig.3, the correlation values R_{pre} and R_{nxt}

are computed according to the following equations (3) and (4).

$$R_{pre} = \sum_{k=1}^{K} abs(E[\hat{Q}_k(n-1) \cdot Q_k(n)^*]) \qquad \text{Equation (3)}$$

$$R_{nxt} = \sum_{k=1}^{K} abs(E[\hat{Q}_k(n+1) \cdot Q_k(n)^*]) \qquad \text{Equation (4)}$$

$Q_k(n)^*$ denotes the conjugated pilot data transmitted using an n^{th} symbol via the a k^{th} sub-carrier , $\hat{Q}_k(n-1)$ denotes the equalized comparison data transmitted using an $(n-1)^{th}$ symbol via a k^{th} sub-carrier, and $\hat{Q}_k(n+1)$ denotes another equalized comparison data transmitted using an $(n+1)^{th}$ symbol via a k^{th} sub-carrier.

Therefore, if the correlation value R_{pre} is greater than the correlation value R_{nxt}, the timing of the boundary is delayed by a small amount of time several times through the timing controller 114; otherwise, the timing is advanced by a small amount of time several times through the timing controller 114. In the end, the ISI effect is alleviated.

It is well-known that the ISI might be introduced by adjacent sub-carriers. That is, inter-carrier-symbol-interference (ICSI) occurs. Please refer to Fig.4, which is a schematic diagram of an ICSI detector 160 according to an embodiment of the present invention. The ICSI detector 160 has two correlators 130, 150 and a comparator 170. The correlator 130 includes a plurality of conjugating units 131, 141; a plurality of equalizers 132a, 132b, 142a, 142b; a plurality of multipliers 133a, 133b, 143a, 143b; a plurality of low-pass filters 134a, 134b, 144a, 144b; a plurality of absolute value calculating units 136a, 136b, 146a, 146b; and a summation unit 138. Similarly, the correlator 150 includes a plurality of conjugating units 151, 161; a plurality of equalizers 152a, 152b, 162a, 162b; a plurality of multipliers 153a, 153b, 163a, 163b; a

plurality of low-pass filters 154a, 154b, 164a, 164b; a plurality of absolute value calculating units 156a, 156b, 166a, 166b; and a summation unit 158.

I t is obvious that the correlators 130, 150 have the same circuit architecture. However, the data inputted into the correlators 130, 140 are different. Please note that the components shown in Figs.2, 3, and 4 that have the same name have identical functionality and operation. The related description, therefore, is not repeated for simplicity. The following equations (5) and (6) are used to better explain operations of the correlators 130 and 150.

$$R_{pre} = \sum_{k=1}^{K} \left(abs(E[\hat{D}_{k-1}(n-1) \cdot D_k(n)^*]) + abs(E[\hat{D}_{k+1}(n-1) \cdot D_k(n)^*]) \right)$$

Equation (5)

$D_k(n)^*$ represents the conjugate of data $D_k(n)$ transmitted using an n^{th} symbol via a k^{th} sub-carrier, $\hat{D}_{k-1}(n-1)$ denotes an equalized result of data $D_{k-1}(n-1)$ transmitted using an $(n-1)^{th}$ symbol via a $(k-1)^{th}$ sub-carrier, and $\hat{D}_{k+1}(n-1)$ denotes an equalized result of data $D_{k+1}(n-1)$ transmitted using an $(n-1)^{th}$ symbol via a $(k+1)^{th}$ sub-carrier. As a result, the correlation value R_{pre} is computed to estimate the magnitude of ICSI imposed upon the data $D_k(n)$. That is, the ICSI generated from the adjacent $(k-1)^{th}$ sub-carrier and $(k+1)^{th}$ sub-carrier using a previous symbol is calculated according to the above Equation (5).

$$R_{nxt} = \sum_{k=1}^{K} \left(abs(E[\hat{D}_{k-1}(n+1) \cdot D_k(n)^*]) + abs(E[\hat{D}_{k+1}(n+1) \cdot D_k(n)^*]) \right)$$

Equation (6)

$D_k(n)^*$ represents the conjugate of data $D_k(n)$ transmitted using an n^{th} symbol via a k^{th} sub-carrier, $\hat{D}_{k-1}(n+1)$ denotes an equalized result of data $D_{k-1}(n+1)$ transmitted using an $(n+1)^{th}$ symbol via a $(k-1)^{th}$ sub-carrier, and $\hat{D}_{k+1}(n+1)$ denotes an equalized result of data $D_{k+1}(n+1)$ transmitted using an $(n+1)^{th}$ symbol via a $(k+1)^{th}$ sub-carrier. It is clear that the correlation value R_{nxt} is also computed to estimate the magnitude of ICSI imposed upon the data $D_k(n)$. In other words, the ICSI generated from the adjacent $(k-1)^{th}$ sub-carrier and $(k+1)^{th}$ sub-carrier using a following symbol is calculated according to the above Equation (6). Please note that data processed by correlators 130 and 150 are transmitted via data sub-carriers not pilot sub-carriers. Finally, the comparator 170 shown in Fig.4 compares the correlation value R_{pre} with the correlation value R_{nxt} for searching a greater one. If the correlation value R_{pre} is greater than the correlation value R_{nxt}, the timing of the boundary would be delayed by a small amount of time several times through the timing controller 172; otherwise, the timing of the boundary of the OFDM system would be advanced by a small amount of time several times. Therefore, the ICSI effect is alleviated.

In the above embodiments, please note the absolute values are directly summed to generate the wanted correlation values R_{pre} and R_{nxt}. However, the correlation values R_{pre} and R_{nxt} can be generated by using square values instead of the absolute values. For instance, each of the product values is squared before the summation value is calculated. That is, the above Equations (1)-(6) are replaced with the following equations, respectively.

$$R_{pre} = \sum_{k=1}^{K} (E[\hat{P}_k(n-1) \cdot P_k(n)^*])^2 \qquad \text{Equation (1.1)}$$

$$R_{nxt} = \sum_{k=1}^{K} (E[\hat{P}_k(n+1) \cdot P_k(n)^*])^2 \qquad \text{Equation (2.1)}$$

$$R_{pre} = \sum_{k=1}^{K} (E[\hat{Q}_k(n-1) \cdot Q_k(n)^*])^2 \qquad \text{Equation (3.1)}$$

$$R_{nxt} = \sum_{k=1}^{K} (E[\hat{Q}_k(n+1) \cdot Q_k(n)^*])^2 \qquad \text{Equation (4.1)}$$

$$R_{pre} = \sum_{k=1}^{K} \left((E[\hat{D}_{k-1}(n-1) \cdot D_k(n)^*])^2 + (E[\hat{D}_{k+1}(n-1) \cdot D_k(n)^*])^2 \right)$$

Equation (5.1)

$$R_{nxt} = \sum_{k=1}^{K} \left((E[\hat{D}_{k-1}(n+1) \cdot D_k(n)^*])^2 + (E[\hat{D}_{k+1}(n+1) \cdot D_k(n)^*])^2 \right)$$

Equation (6.1)

In contrast to the prior art, the method and related device of detecting ISI/ICSI in an OFDM system for tuning a boundary of the OFDM system according to the present invention first computes correlation values to predict the source of the ISI/ICSI. After the source of the ISI/ICSI is determined, the boundary is tuned gradually and precisely. Therefore, the performance of tracking the boundary for the OFDM system is greatly improved.

Those skilled in the art will readily observe that numerous modifications and alterations of the device and method may be made while retaining the teachings of the invention. Accordingly, the above disclosure should be construed as limited only by the metes and bounds of the appended claims.

Claims

1. A method of detecting inter-symbol interference (ISI) in an OFDM system for tuning a boundary utilized by the OFDM system wherein a plurality of pilot data are respectively transmitted via the same pilot sub-carrier using different symbols, the method comprising:
   computing a first correlation value according to both a pilot data transmitted via a pilot sub-carrier using a current symbol and a first comparison data corresponding to a pilot data transmitted via the pilot sub-carrier using a previous symbol;
   computing a second correlation value according to both the pilot data using the current symbol and a second comparison data corresponding to a pilot data transmitted via the pilot sub-carrier using a next symbol;
   comparing the first correlation value with the second correlation value; and
   delaying timing of the boundary if the first correlation value is greater than the second correlation value, and advancing timing of the boundary if the first correlation value is not greater than the second correlation value.

2. The method of claim 1 wherein the step of computing the first correlation value comprises:
   conjugating the pilot data transmitted using the current symbol for producing a conjugated pilot data;
   multiplying the first comparison data by the conjugated pilot data for generating a product value; and
   generating the first correlation value according to the product value.

3. The method of claim 1 wherein the step of computing the second correlation value comprises:
   conjugating the pilot data transmitted using the current symbol for producing a conjugated pilot data;
   multiplying the second comparison data by the conjugated pilot data for generating a product value; and
   generating the second correlation value according to the product value.

4. The method of claim 1 wherein when the pilot data transmitted via the same pilot sub-carrier using different symbols have the same value, the method further comprises:
   equalizing the pilot data transmitted using the previous symbol for generating the first comparison data; and

equalizing the pilot data transmitted using the next symbol for generating the second comparison data.

5. The method of claim 1 wherein when the pilot data respectively transmitted via the same pilot sub-carrier using different symbols have known predetermined values, the method further comprises:
selecting a known pilot data corresponding to the pilot data transmitted using the previous symbol as the first comparison data; and
selecting a known pilot data corresponding to the pilot data transmitted using the next symbol as the second comparison data.

6. A method of detecting inter-carrier-symbol interference (ICSI) in an OFDM system for tuning a boundary utilized by the OFDM system, the method comprising:
computing a first correlation value according to a first data transmitted using a current symbol via a first sub-carrier and a second data transmitted using a previous symbol via a second sub-carrier;
computing a second correlation value according to the first data transmitted using the current symbol and a third data transmitted using a next symbol by the second sub-carrier;
comparing the first correlation value with the second correlation value; and
delaying timing of a boundary of the OFDM system if the first correlation value is greater than the second correlation value, and advancing timing of the boundary of the OFDM system if the first correlation value is not greater than the second correlation value.

7. The method of claim 6 wherein the step of computing the first correlation value comprises:
equalizing the second data transmitted using the previous symbol for generating an equalized data;
conjugating the first data transmitted using the current symbol for generating a conjugated data;
multiplying the equalized data that uses the previous symbol by the conjugated data that uses the current symbol for generating a product value; and
generating the first correlation value according to the product value.

8. The method of claim 6 wherein the step of computing the second correlation value comprises:

equalizing the third data transmitted using the next symbol for producing an equalized data;

conjugating the first data transmitted using the current symbol for producing a conjugated data;

multiplying the equalized data that uses the next symbol by the conjugated data that uses the current symbol for generating a product value; and

generating the second correlation value according to the product value.

9. An apparatus of detecting inter-symbol interference (ISI) in an OFDM system for tuning a boundary utilized by the OFDM system, wherein a plurality of pilot data are respectively transmitted via the same pilot sub-carrier using different symbols, the apparatus comprising:

a first correlator for computing a first correlation value according to both a pilot data transmitted using a current symbol via a pilot sub-carrier and a first comparison pilot data corresponding to a pilot data transmitted using a previous symbol via the pilot sub-carrier;

a second correlator for computing a second correlation value according to both the pilot data transmitted using the current symbol and a second comparison pilot data corresponding to a pilot data transmitted using a next symbol via the pilot sub-carrier;

a comparator connected to the first correlator and the second correlator for generating a control signal; and

a timing controller connected to the comparator for shifting timing of the boundary according to the control signal, wherein the timing controller delays timing of the boundary if the first correlation value is greater than the second correlation value, and advances timing of the boundary if the first correlation value is not greater than the second correlation value.

10.The apparatus of claim 9 wherein the first correlator comprises:

a conjugating unit for generating a conjugated pilot data according to the pilot data transmitted using the current symbol;

a multiplier connected to the conjugating unit for generating a product value according to the conjugated pilot data and the first comparison data; and

an absolute value calculating unit connected to the multiplier for generating the first correlation value according to the product value.

11. The apparatus of claim 9 wherein the second correlator comprises:

a conjugating unit for generating a conjugated pilot data according to the pilot

data transmitted using the current symbol;

a multiplier connected to the conjugating unit for generating a product value according to the conjugated pilot data and the second comparison data; and

an absolute value calculating unit connected to the multiplier for generating the second correlation value according to the product value.

12. The apparatus of claim 9 wherein when the pilot data respectively transmitted via the same pilot sub-carrier using different symbols have the same value, the detector further comprises:

an equalizer connected to a multiplier for equalizing the pilot data that uses the previous symbol and generating the first comparison data accordingly; and

an equalizer connected to a multiplier for equalizing the pilot data that uses the next symbol and generating the second comparison data accordingly.

13.The apparatus of claim 9 wherein the pilot data respectively transmitted via the same pilot sub-carrier using different symbols have known predetermined values.

14. An apparatus of detecting inter-carrier-symbol interference (ICSI) in an OFDM system for tuning a boundary utilized by the OFDM system, the apparatus comprising:

a first correlator, for computing a first correlation value according to a first data transmitted using a current symbol via a first sub-carrier and a second data transmitted using a previous symbol via a second sub-carrier;

a second correlator for computing a next correlation value according to the first data transmitted using the current symbol and a third data transmitted using a next symbol via the second sub-carrier;

a comparator connected to the first correlator and the second correlator for generating a control signal according to the first and second correlation value; and

a timing controller connected to the comparator for shifting the timing of a boundary of the OFDM system according to the control signal, wherein the timing controller delays timing of the boundary if the first correlation value is greater than the second correlation value, and advances timing of the boundary if the first correlation value is not greater than the second correlation value.

15. The apparatus of claim 14 wherein the first correlator comprises:

a conjugating unit for generating a conjugated data according to the first data transmitted using the current symbol ;

an equalizer for generating an equalized data according to the second data transmitted using the previous symbol;

a multiplier connected to the equalizer and the conjugating unit for generating a product value according to the equalized data and the conjugated data; and

an absolute value calculating unit connected to the multiplier for generating the first correlation value according to the product value.

16.The apparatus of claim 14 wherein the second correlator comprises:

a conjugating unit for generating a conjugated data according to the first data transmitted using the current symbol ;

an equalizer for generating an equalized data according to the third data transmitted using the next symbol;

a multiplier connected to the equalizer and the conjugating unit for generating a product value according to the equalized data and the conjugated data; and

an absolute value calculating unit connected to the multiplier for generating the second correlation value according to the product value.

Abstract of Disclosure

A method for detecting inter-symbol interference (ISI) in an OFDM system includes computing a first correlation value according to a pilot data transmitted using a current symbol via a pilot sub-carrier and a first comparison data corresponding to a pilot data transmitted using a previous symbol via the pilot sub-carrier; computing a second correlation value according to the pilot data using the current symbol and a second comparison data corresponding to a pilot data transmitted using a next symbol via the pilot sub-carrier; comparing the first correlation value with the second correlation value; and delaying timing of a boundary of the OFDM system if the first correlation value is greater than the second correlation value, and advancing timing of the boundary of the OFDM system if the first correlation value is not greater than the second correlation value.

Figures

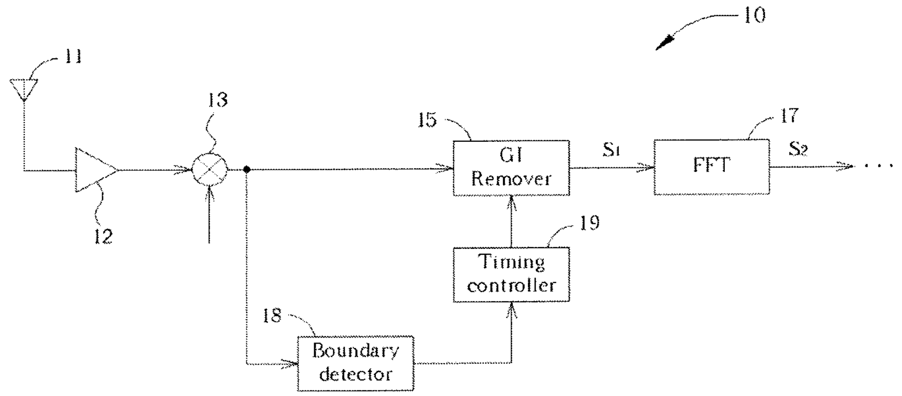


Fig. 1 Prior art

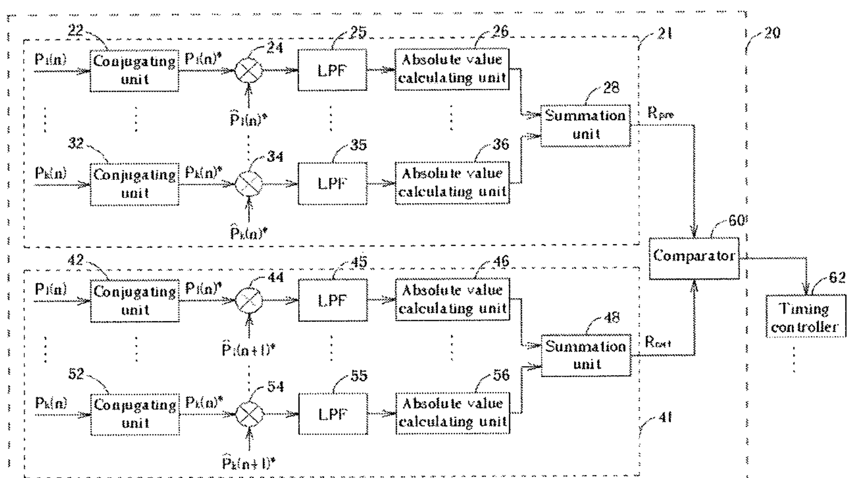


Fig. 2

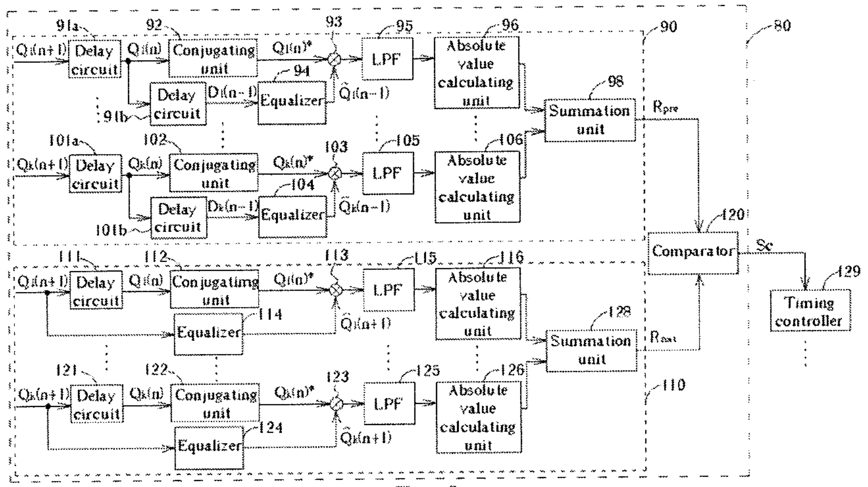
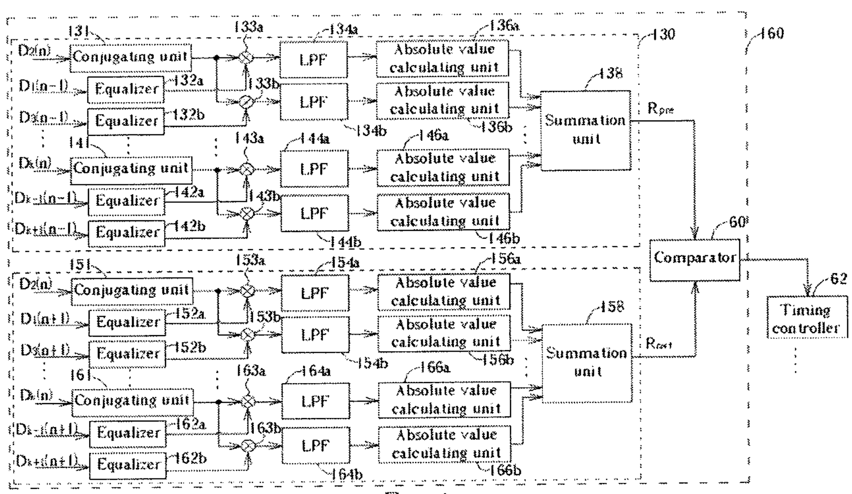

Delay circuit
Conjugating unit
LPF
Absolute value calculating unit
Delay circuit
Equalizer
Summation unit
Delay circuit
Conjugating unit
LPF
Absolute value calculating unit
Delay circuit
Equalizer
Comparator
Sc
Rpre
Delay circuit
Conjugating unit
LPF
Absolute value calculating unit
Equalizer
Summation unit
Rnext
Timing controller
Delay circuit
Conjugating unit
LPF
Absolute value calculating unit
Equalizer

Fig. 3


Conjugating unit
Equalizer
Equalizer
LPF
LPF
Absolute value calculating unit
Absolute value calculating unit
Summation unit
Rpre
Conjugating unit
Equalizer
Equalizer
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Absolute value calculating unit
Absolute value calculating unit
Comparator
Conjugating unit
Equalizer
Equalizer
LPF
LPF
Absolute value calculating unit
Absolute value calculating unit
Summation unit
Rnext
Timing controller
Conjugating unit
Equalizer
Equalizer
LPF
LPF
Absolute value calculating unit
Absolute value calculating unit

Fig. 4

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主旨： 瑞昱93A-117及93A-023(REA-P0087-USA)之初稿回擲
日期： 2004年6月14日 下午 03:55:52
附件： 93A-023USD1B.DOC
93A-117USD1B.DOC

Dear all,

附加檔案為我方之校稿回擲，請參照。
關於93A-117之圖示及內文修改的部分，請參照93A-023之修改方式修改。
93A-117之發明人為卓俊銘與顏光裕，請Candice儘速準備發明人簽名文件。
另，93A-117與93A-023請於同一天送USPTO申請。
此兩案皆需回傳我須二校。

感謝貴所的費心處理。

Best Regards,
Matt

(See attached file: 93A-023USD1B.DOC)(See attached file: 93A-117USD1B.DOC)

並設定為第一頁，因此本文起始處的頁數不會變動。

(2) 請於各個段落之間加註意見。加註時請於相關問題發生段落之起始處或是結尾處插入另一段落，加註修正意見之段落請使用紅色字體並於頭尾加上"【修正意見：】"的標記。

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【修正意見：　】

Title

METHOD AND APPARATUS OF DETECTING ISI/ICSI IN AN OFDM SYSTEM ~~FOR CORRECTLY TUNING A BOUNDARY UTILIZED BY THE OFDM SYSTEM~~

Cross Reference To Related Applications

This is a co-pending Application No. XX/XXXXXX, filed on the same day with the present patent application, entitled "METHOD AND APPARATUS OF DETECTING ISI/ICSI IN AN OFDM SYSTEM" and assigned to the same assignee, the contents of which are incorporated herein by reference.

Background of Invention

1. Field of the Invention

The invention relates to an apparatus for use in an OFDM system and a method thereof ~~and a method of tuning a boundary of an OFDM system~~, and more particularly, to ~~a method and~~ an apparatus for ~~of~~ detecting ISI/ICS~~I~~ in an OFDM system and a method thereof~~for correctly tuning a boundary utilized by the OFDM system~~.

2. Description of the Prior Art

* 在描述 prior art 時，除非是發明人提供的，否則最好不要自己 create 圖。另，對 prior art 的描述不需要太詳細。可以請發明人多提供相關資料 (paper/patent)，以 IDS(information disclosure statement) 方式提出。

~~Generally speaking, m~~Most OFDM transceivers suffer from well-known problems of inter-symbol interference (ISI) and inter-carrier interference (ICI). An

additional guard interval (GI) is added between two symbols ~~Therefore, some slices in a packet of the OFDM transceiver are reserved for a plurality of guard intervals (GI)~~ to recover ~~reduce the influence of~~ the ISI and the ICI. When receiving a packet including a plurality of symbols, ~~Please refer to Fig.1, which is a schematic diagram of a~~ a conventional ~~prior art~~ OFDM receiver ~~10. As shown in Fig.1, the OFDM receiver 10 comprises a boundary detector 18 for~~ detects ~~ing~~ the ~~a~~ boundary of each symbol,s ~~, a GI remover 15 for~~ removes ~~ing a plurality of~~ GI~~s~~ of ~~in~~ each symbol according to the detected boundary of the symbol, and then demodulated the symbol through F~~and outputting the data S1, a~~ fast ~~f~~Fourier ~~t~~Transform~~er~~ (FFT) operation. If the~~17 for demodulating the data S1 transmitted via different sub-carriers using each symbol to output the demodulated data S2, and a timing controller 19 for providing timing to the GI remover 15 to triggering the removal of GIs. However, the~~ detected boundary of the symbols is ~~may~~ not ~~be~~ reliable owing to the ~~influence of~~ multi-path effect and other factors, the ISI and ICI problems may still occur.

One conventional ~~prior~~ art applied to improve the precision of boundary detection is to estimate the time shift of the detected boundary according to ~~solve this problem detects~~ the frequency domain linear phase shift of the demodulated data, ~~S_2, estimates the time shift of the transmitted data S_1 caused by the time shift of the detected boundary according to the FFT theorem, and then shifts the timing of the boundary for a determined distance according to the time shift. That is, the boundary is shifted to a correct position within the packet.~~ Another conventional ~~prior~~ art disclosed is to estimate the time shift of the detected boundary according to the ~~estimates the time shift of the boundary through the~~ channel impulse response of the symbol. H~~, and then shifts the timing of the boundary for a determined distance according to the time shift.~~

——owever,~~Unfortunately,~~ when the delay spread phenomenon is too severe, the ISI and ICI problem cannot be recovered by both of the ~~ose~~ two conventional ~~prior art~~ techniques and the boundary detection –may be ~~cause~~ imprecise which may cause divergence or even failure in receiving when receiving symbols. ~~, which seriously damages the reliability of the OFDM receiver 10. It is because those two prior art techniques adjust the boundary too fast by shifting the boundary by a determined distance. The boundary detector 18 may make a mistake in detecting the required boundary. In other words, an erroneous boundary is detected by the boundary detector 18 when the surrounding environment is full of noise. Therefore, it's difficult to tune the boundary back to a correct position according to the erroneously detected boundary. As a result, the OFDM receiver 10 may malfunction. Furthermore, the tuning range of those two prior art techniques are small. That is to say, the accuracy of boundary detector 18 is required. How to correctly tune the boundary is very important for the OFDM receiver 10 in order to extract the wanted data from the received packet.~~

Summary of Invention

It is therefore one of the objects ~~ives~~ of the claimed invention to provide a method and an apparatus of detecting ISI/ICSI in an OFDM system for use in boundary tracking ~~correctly tuning a boundary~~ utilized by the OFDM system to solve the above-mentioned problem.

According to an embodiment of the claimed invention, a method of detecting inter-symbol interference (ISI) of a symbol for adjusting a boundary of the symbol utilized by an OFDM system is disclosed. Each symbol includes a plurality of

signals respectively transmitting via a plurality of sub-carriers. The disclosed method comprises the steps of computing a first correlation value representing the correlation between a plurality of first signals of a first symbol and a plurality of second signals of a second symbol previous to the first symbol, wherein the first and the second signals are both transmitted via the same sub-carriers and the value of the first and the second signals are different; computing a second correlation value representing the correlation between the first signals and a plurality of third signals of a third symbol next to the first symbol, wherein the first and the third signals are both transmitted via the same sub-carriers and the value of the first and the third signals are different ; comparing the first correlation value with the second correlation value; and adjusting the timing of the boundary according to the comparison result. ~~an ISI detector is disclosed. The ISI detector comprises a first correlator for computing a first correlation value according to a pilot data transmitted using a current symbol via a pilot sub-carrier and a first comparison data corresponding to a pilot data transmitted using a previous symbol via the pilot sub-carrier; a second correlator for computing a second correlation value according to the pilot data transmitted using the current symbol and a second comparison data corresponding to a pilot data transmitted using the next symbol via the pilot sub-carrier; a comparator connected to the first correlator and the second correlator for generating a control signal; and a timing controller connected to the comparator for shifting the timing of a boundary of the OFDM system according to the control signal.~~

According to an embodiment of the claimed invention, an apparatus of detecting inter-symbol interference (ISI) of a symbol for adjusting a boundary of the symbol utilized by an OFDM system is disclosed. Each symbol includes a plurality of signals respectively transmitting via a plurality of sub-carriers. The disclosed

apparatus comprises a first correlator for computing a first correlation value representing the correlation between a plurality of first signals of a first symbol and a plurality of second signals of a second symbol previous to the first symbol, wherein the first and the second signals are both transmitted via the same sub-carriers and the value of the first and the second signals are different; a second correlator for computing a second correlation value representing the correlation between the first signals and a plurality of third symbols of a third symbol next to the first symbol, wherein the first and the third signals are both transmitted via the same sub-carriers and the value of the first and the third signals are different; a comparator for comparing the first correlation value with the second correlation value; and a timing controller for adjusting the timing of the boundary according to the comparison result.~~an ICSI detector is disclosed. The ICSI detector comprises a first correlator for computing a first correlation value according to a first data transmitted using a current symbol via a first sub-carrier and a second data transmitted using a previous symbol via a second sub-carrier ; a second correlator for computing a next correlation value according to the first data transmitted using the current symbol and a third data transmitted using a next symbol by the second sub-carrier ; a comparator connected to the first correlator and the second correlator for generating a control signal; and a timing controller connected to the comparator for shifting the timing of a boundary of the OFDM system according to the control signal.~~

Brief Description of Drawings

~~Fig.1 is a schematic diagram of a prior art OFDM receiver.~~

Fig.~~2~~1 is a schematic diagram of an ISI detector according to one embodiment of the present invention.

Fig.~~3~~2 is a schematic diagram of an ISI detector according to another embodiment of

the present invention.

Fig.~~4~~3 is a schematic diagram of an ICSI detector according to an embodiment of the present invention.

Detailed Description

~~In order to solve the problem mentioned above, the primary objective of the invention provides an ISI/ICSI detector and a related method for detecting the source where the interference is introduced. Then, the boundary is shifted away from the source by a very small distance repeatedly, which reduces the influence of ISI/ICSI gradually.~~

Please refer to Fig.~~2~~1, which is a schematic diagram of an ISI detector 20 according to one embodiment of the present invention. As shown in Fig.~~2~~1, the ISI detector 20 is coupled ~~connected~~ (直接連接用 connect，信號連結用 couple。通常電路都用 couple) to a timing controller 62, and the ISI detector 20 comprises two correlators 21, 41 for respectively generating a correlation value R_{pre} and a correlation value R_{nxt} and a comparator 60 to compare both correlation values~~. The correlators 21, 41 are used for respectively generating a correlation value R_{pre} and a correlation value R_{nxt}~~. The correlation value R_{pre} ~~s~~represents ~~tands for~~ the magnitude of the ISI caused by the ~~generated from a~~ previous symbol, and the correlation value R_{nxt} ~~s~~represents ~~tands for~~ the magnitude of the ISI caused by the ~~generated from a~~ next symbol. The comparator 60 is used to compare the correlation value R_{pre} with the correlation value R_{nxt} and generate a control signal Sc according to the comparison result. The timing controller 62 ~~has the same functionality as that of the timing controller 19 shown in Fig.1. That is, the timing controller 62 in this preferred embodiment~~ is used to control the timing of a boundary of an OFDM system according to the control signal Sc.

As shown in Fig.~~2~~1, the correlator 21 of this embodiment comprises ~~a plurality of~~ conjugating units 22,......, 32, ~~; a plurality of~~ multipliers 24,......, 34, ~~; a plurality of~~ low-pass filters 25,......, 35, ~~; a plurality of~~ absolute value calculating units 26,......, 36, ~~;~~ and a summation unit 28. The conjugating units 22,......, 32 are used for respectively generating conjugated pilot data $P_1(n)^*$,......, $P_k(n)^*$ by conjugating corresponding pilot data $P_1(n)$,......, $P_k(n)$ that was transmitted using ~~a~~the current symbol. The multipliers 24,......, 34 are used for respectively generating product values by multiplying those conjugated pilot data $P_1(n)^*$, $P_k(n)^*$ with a corresponding comparison data $\hat{P}_1(n-1)$,......, $\hat{P}_k(n-1)$ that was transmitted using ~~a~~the previous symbol. The low-pass filters 25,......, 35 are used for averaging the product values outputted from these multipliers 24, 34, respectively. The absolute value calculating units 26,......, 36 are used for generating absolute values of the average values corresponding to the product values. The summation unit 28 is used for generating a correlation value R_{pre} by summing these absolute values.

Similarly, the correlator 41 comprises ~~a plurality of~~ conjugating units 42,......, 52, ~~; a plurality of~~ multipliers 44,......, 54, ~~; a plurality of~~ low-pass filters 45,......, 55, ~~; a plurality of~~ absolute value calculating units 46,......, 56, ~~;~~ and a summation unit 48. The conjugating units 42,......, 52 are used for respectively generating conjugated pilot data $P_1(n)^*$,......, $P_k(n)^*$ by conjugating corresponding pilot data $P_1(n)$, $P_k(n)$ that was transmitted using a current symbol. The multipliers 44,......, 54 are used for respectively generating product values by multiplying those conjugated pilot data $P_1(n)^*$,......, $P_k(n)^*$ with a corresponding comparison data $\hat{P}_1(n+1)$,......, $\hat{P}_k(n+1)$ that was transmitted using ~~a~~the next symbol. The low-pass filters 45,......, 55 are used for averaging the product values outputted from these multipliers 44, 54, respectively. The absolute value calculating units 46,......, 56 are used for generating

absolute values of the average values corresponding to the product values outputted from these multipliers 44, 54. The summation unit 48 is used for generating a correlation value R_{nxt} by summing these absolute values.

According to the well-known theorem of correlation, the following Equations (1) and (2) are used to better explain operations of the correlators 21, 41.

$$R_{pre} = \sum_{k=1}^{K} abs(E[\hat{P}_k(n-1) \cdot P_k(n)^*]) \qquad \text{Equation (1)}$$

$$R_{nxt} = \sum_{k=1}^{K} abs(E[\hat{P}_k(n+1) \cdot P_k(n)^*]) \qquad \text{Equation (2)}$$

$P_k(n)^*$ denotes the conjugated pilot data transmitted using an n^{th} symbol via the a k^{th} sub-carrier, $\hat{P}_k(n-1)$ denotes the comparison data transmitted using an $(n-1)^{th}$ symbol via a k^{th} sub-carrier, and $\hat{P}_k(n+1)$ denotes another comparison data transmitted using an $(n+1)^{th}$ symbol via a k^{th} sub-carrier. Please note that the more sub-carriers that are considered, the more reliable result will be generated.

This embodiment of ISI detector is for use ~~I~~in the ~~some~~ OFDM system that ~~s,~~ the pilot ~~data~~ of different symbols transmitted via the same pilot sub-carrier ~~using different symbols~~ have known but different predetermined values. In this embodiment, ~~Therefore,~~ $\hat{P}_k(n-1)$ and $\hat{P}_k(n+1)$ ~~in the above embodiment~~ denote those known predetermined values of pilot ~~data~~. Since the pilots of two different symbols are different, the correlation between pilot of different symbols is due to the interference between these two symbols. Therefore, ~~I~~if the correlation value R_{pre} is greater than the correlation value R_{nxt}, it means that the interference is mainly introduced from using the previous symbol, which ~~; this~~ is due to ~~the fact that~~ the timing of the ~~actual~~detected boundary is ahead of ~~leads~~ that of the ideal boundary. In this manner,

~~Therefore, the comparator 60 outputs the control signal Sc to~~ the timing controller 62 ~~for~~ delays ~~ing~~ the timing of the ~~actual~~ boundary according to the control signal Sc outputted from the comparator 60. On the other hand, if the correlation value R_{pre} is less than the correlation value R_{nxt}, it means that the interference is mainly introduced from using the following symbol, which ~~; this~~ is due to ~~the fact that~~ the timing of the ~~actual~~ detected boundary lags behind that of the ideal boundary. In this manner, ~~Therefore,~~ the comparator 60 outputs the control signal Sc to the timing controller 62 for advancing the timing of the ~~actual~~ boundary. As a result, the ISI effect is alleviated.

Please refer to Fig.~~3~~2, which is a schematic diagram of an ISI detector 80 according to another embodiment of the present invention. As show in Fig.~~3~~2, the ISI detector 80 comprises two correlators 90, 110 and a comparator 120. The correlators 90, 110 are used for generating correlation values R_{pre} and R_{nxt}, respectively. The comparator 120 compares the correlation value R_{pre} with the correlation value R_{nxt} for outputting a control signal Sc to control the timing controller 129.

In some OFDM systems, the pilot data of different symbols transmitted via the same pilot sub-carrier have known and the same values. This embodiment of ISI detector 80 shown in Fig. 2 is for use in this kind of OFDM system. In this embodiment, k sub-carriers for transmitting data are chosen through decision directed method for determining ISI. Since the data of two different symbols transmitted via the same sub-carrier are different, the correlation between the data of different symbols is due to the interference between these two symbols.

In this ~~preferred~~ embodiment, the correlator 90 has 1^{st} ~~a plurality of~~ delay circuits 91a, ~~91b,~~ ……, 101a, 2^{nd} delay circuits 91b, ……, 101b~~101b~~, ~~; a plurality of~~ conjugating units 92, ……, 102, ~~; a plurality of~~ multipliers 93, ……, 103, ~~; a plurality of~~ equalizers 94, ……, 104, ~~; a plurality of~~ slicers (對應的標號)~~(equalizer 後還需要加一個 slicer，表示對 data 做 decision)~~, ~~; a plurality of~~ low-pass filters 95, ……, 105, ~~; a plurality of~~ absolute value calculating units 96, ……, 106, ~~;~~ and a summation unit 98. Concerning the other correlator 110, it has 1^{st} ~~a plurality of~~ delay circuits 111, ……, 121, ~~; a plurality of~~ conjugating units 112, ……, 122, ~~; a plurality of~~ multipliers 113, ……, 123, ~~; a plurality of~~ equalizers 114, ……, 124, slicers (對應的標號), ~~; a plurality of~~ low-pass filters 115, ……, 125, ~~; a plurality of~~ absolute value calculating units 116, ……, 126, ~~;~~ and a summation unit 128. Please note that the components shown in Figs.~~2~~1 and ~~3~~2 that have the same name have substantially the same ~~identical~~ (通常不會用 identical 這麼強烈的詞，都是用 substantially the same)functionality and operation. The related description, therefore, is not repeated for simplicity.

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~~The major difference between the correlators 90, 110 shown in Fig.3 and the correlators 21, 41 shown in Fig.2 is the configuration of the delay circuits 91a, 91b, 101a, 101b and the equalizers 94, 104, 114, 124.~~

For an OFDM system having pilot ~~data~~ transmitted via the same pilot sub-carrier using different symbols corresponding to the same ~~an identical~~ value, the ISI detector 80 is preferably utilized. As shown in Fig.~~3~~2, the comparison data $\hat{Q}_1(n-1)$ and $\hat{Q}_k(n-1)$ are the decision results from received data signal ~~generated by equalizing the pilot data~~ Q_1(n-1) and Q_k(n-1) through the corresponding equalizers 94, ~~and~~ ……, 104, and the slicers (標號), wherein the ~~pilot~~ data Q_1(n-1), ……, ~~and~~

$Q_k(n-1)$ are delayed ~~and transmitted to the equalizers 94 and 104~~ by the corresponding 1st delay circuits 91a,……~~91b,~~ 101a, 2nd delat circuits 91b,……,101b and then transmitted to the equalizers 94,……,104. Regarding the comparison data $\hat{Q}_1(n+1)$ and $\hat{Q}_k(n+1)$, they are generated by directly equalizing and slicing the ~~pilot~~ data $Q_1(n+1)$ and $Q_k(n+1)$ with the corresponding equalizers 114,……~~and~~ 124 and slicers (標號).

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It should be noted that the symbol Q(.) represents the received data signal of the corresponding ~~為 d~~data sub-carrier and the symbol $\hat{Q}$ (.) represents the result of equalizing and slicing of the data signal ~~上 received data signal，Q hat(.)為~~ of Q(.) ~~經過 Equalizer，Slicer 後 decision 的結果.~~

With the circuit configuration shown in Fig.~~3~~2, the correlation values R_{pre} and R_{nxt} are computed according to the following equations (3) and (4).

$$R_{pre} = \sum_{k=1}^{K} abs(E[\hat{Q}_k(n-1) \cdot Q_k(n)^*]) \qquad \text{Equation (3)}$$

$$R_{nxt} = \sum_{k=1}^{K} abs(E[\hat{Q}_k(n+1) \cdot Q_k(n)^*]) \qquad \text{Equation (4)}$$

$Q_k(n)^*$ denotes the conjugated ~~pilot~~ data transmitted using an n^{th} symbol via the a k^{th} sub-carrier, $\hat{Q}_k(n-1)$ denotes the equalized comparison data transmitted using an $(n-1)^{th}$ symbol via a k^{th} sub-carrier, and $\hat{Q}_k(n+1)$ denotes another equalized comparison data transmitted using an $(n+1)^{th}$ symbol via a k^{th} sub-carrier.

Therefore, if the correlation value R_{pre} is greater than the correlation value R_{nxt}, it means that the interference is mainly caused by the previous symbol, in this manner, the timing of the boundary is delayed by ~~a small amount of time several times through~~

the timing controller 114. If the correlation value R_{pre} is smaller than the correlation value R_{nxt}, it means that the interference is mainly caused by the next symbol, in this manner, ~~; otherwise,~~ the timing is advanced by ~~a small amount of time several times through~~ the timing controller 114. In the end, the ISI effect is alleviated.

It is well-known that the ISI might be introduced by adjacent sub-carriers as well. That is, inter-carrier-symbol-interference (ICSI) occurs. Please refer to Fig.~~4~~3, which is a schematic diagram of an ICSI detector 160 according to the third ~~an~~ embodiment of the present invention. In this embodiment, k sub-carriers of the different symbols for transmitting data are chosen through decision directed method for determining ISI. Since the data of two different sub-carriers are different, the correlation between the data of different sub-carriers is due to the interference between these two sub-carriers.

The ICSI detector 160 has two correlators 130, 150 and a comparator 170. The correlator 130 includes ~~a plurality of~~ conjugating units 131, ..., 141, ~~; a plurality of~~ equalizers 132a, ~~-~~132b, ..., 142a, 142b, ~~; a plurality of~~ slicers ~~(equalizer 後還需要加一個 slicer，表示對 data 做 decision~~(標號), ~~; a plurality of~~ multipliers 133a, 133b, ..., 143a, 143b, ~~; a plurality of~~ low-pass filters 134a, 134b, ..., 144a, 144b, ~~; a plurality of~~ absolute value calculating units 136a, 136b, ..., 146a, 146b, ~~;~~ and a summation unit 138. Similarly, the correlator 150 includes ~~a plurality of~~ conjugating units 151, ..., 161, ~~; a plurality of~~ equalizers 152a, 152b, ..., 162a, 162b, slicers (標號), ~~; a plurality of~~ multipliers 153a, 153b, ..., 163a, 163b, ~~; a plurality of~~ low-pass filters 154a, 154b, ..., 164a, 164b, ~~; a plurality of~~ absolute value calculating units 156a, 156b, ..., 166a, 166b, ~~;~~ and a summation unit 158.

I t is obvious that the correlators 130, 150 have ~~the~~ substantially the same circuit architecture. However, the data inputted into the correlators 130, 140 are different. Please note that the components shown in Figs. ~~2~~1, ~~3~~2, and ~~4~~3 that have the same name have substantially the same ~~identical~~ functionality and operation. The related description, therefore, is not repeated for simplicity. The following equations (5) and (6) are used to better explain operations of the correlators 130 and 150.

$$R_{pre} = \sum_{k=1}^{K} \left(abs(E[\hat{D}_{k-1}(n-1) \cdot D_k(n)^*]) + abs(E[\hat{D}_{k+1}(n-1) \cdot D_k(n)^*]) \right)$$

Equation (5)

$D_k(n)^*$ represents the conjugate of data $D_k(n)$ transmitted using an n^{th} symbol via a k^{th} sub-carrier, $\hat{D}_{k-1}(n-1)$ denotes ~~an equalized~~a decision result of data $D_{k-1}(n-1)$ transmitted using an $(n-1)^{th}$ symbol via a $(k-1)^{th}$ sub-carrier, and $\hat{D}_{k+1}(n-1)$ denotes ~~an equalized~~a decision result of data $D_{k+1}(n-1)$ transmitted using an $(n-1)^{th}$ symbol via a $(k+1)^{th}$ sub-carrier. As a result, the correlation value R_{pre} is computed to estimate the magnitude of ICSI imposed upon the data $D_k(n)$. That is, the ICSI generated from the adjacent $(k-1)^{th}$ sub-carrier and $(k+1)^{th}$ sub-carrier using a previous symbol is calculated according to the above Equation (5).

$$R_{nxt} = \sum_{k=1}^{K} \left(abs(E[\hat{D}_{k-1}(n+1) \cdot D_k(n)^*]) + abs(E[\hat{D}_{k+1}(n+1) \cdot D_k(n)^*]) \right)$$

Equation (6)

$D_k(n)^*$ represents the conjugate of data $D_k(n)$ transmitted using an n^{th} symbol via a k^{th} sub-carrier, $\hat{D}_{k-1}(n+1)$ denotes ~~an equalized~~a decision result of data $D_{k-1}(n+1)$ transmitted using an $(n+1)^{th}$ symbol via a $(k-1)^{th}$ sub-carrier, and $\hat{D}_{k+1}(n+1)$ denotes

~~an equalized~~a decision result of data $D_{k+1}(n+1)$ transmitted using an $(n+1)^{th}$ symbol via a $(k+1)^{th}$ sub-carrier. It is clear that the correlation value R_{nxt} is also computed to estimate the magnitude of ICSI imposed upon the data $D_k(n)$. In other words, the ICSI generated from the adjacent $(k-1)^{th}$ sub-carrier and $(k+1)^{th}$ sub-carrier using a following symbol is calculated according to the above Equation (6). Please note that data processed by correlators 130 and 150 are transmitted via data sub-carriers not pilot sub-carriers. Finally, the comparator 170 shown in Fig.43 compares the correlation value R_{pre} with the correlation value R_{nxt} for searching a greater one. If the correlation value R_{pre} is greater than the correlation value R_{nxt}, it means that the interference is mainly caused by the previous symbol, in this manner, the timing of the boundary would be delayed by ~~a small amount of time several times through~~ the timing controller 172. If the correlation value R_{pre} is smaller than the correlation value R_{nxt}, it means that the interference is mainly caused by the next symbol, in this manner, ~~; otherwise,~~ the timing of the boundary of the OFDM system would be advanced by the timing controller 172~~a small amount of time several times~~. Therefore, the ICSI effect is alleviated.

In the above embodiments, please note the absolute values are directly summed to generate the wanted correlation values R_{pre} and R_{nxt}. However, the correlation values R_{pre} and R_{nxt} can be generated by using square values instead of the absolute values. For instance, each of the product values is squared before the summation value is calculated. That is, the above Equations (1)-(6) are replaced with the following equations, respectively.

$$R_{pre} = \sum_{k=1}^{K} (E[\hat{P}_k(n-1) \cdot P_k(n)^*])^2 \qquad \text{Equation (1.1)}$$

$$R_{nxt} = \sum_{k=1}^{K} (E[\hat{P}_k(n+1) \cdot P_k(n)^*])^2$$ Equation (2.1)

$$R_{pre} = \sum_{k=1}^{K} (E[\hat{Q}_k(n-1) \cdot Q_k(n)^*])^2$$ Equation (3.1)

$$R_{nxt} = \sum_{k=1}^{K} (E[\hat{Q}_k(n+1) \cdot Q_k(n)^*])^2$$ Equation (4.1)

$$R_{pre} = \sum_{k=1}^{K} \left((E[\hat{D}_{k-1}(n-1) \cdot D_k(n)^*])^2 + (E[\hat{D}_{k+1}(n-1) \cdot D_k(n)^*])^2 \right)$$

Equation (5.1)

$$R_{nxt} = \sum_{k=1}^{K} \left((E[\hat{D}_{k-1}(n+1) \cdot D_k(n)^*])^2 + (E[\hat{D}_{k+1}(n+1) \cdot D_k(n)^*])^2 \right)$$

Equation (6.1)

~~In contrast to the prior art, t~~The method and related device disclosed in the embodiments of the present invention for ~~of~~ detecting ISI/ICSI in an OFDM system for adjusting ~~tuning~~ a boundary of the OFDM system ~~according to the present invention~~ first computes correlation values to predict the source of the ISI/ICSI ~~,~~ and then adjusting the boundary ~~A~~after the source of the ISI/ICSI is determined~~, the boundary is tuned gradually and precisely~~. Therefore, the performance of tracking the boundary of ~~for~~ the OFDM system is greatly improved.

Those skilled in the art will readily observe that numerous modifications and alterations of the device and method may be made while retaining the teachings of the invention. Accordingly, the above disclosure should be construed as limited only by the metes and bounds of the appended claims.

Claims

1. A method of detecting inter-symbol interference (ISI) of a symbol ~~in an OFDM system~~ for adjusting ~~tuning~~ a boundary of the symbol utilized by an ~~the~~ OFDM system, wherein each symbol includes a plurality of signals ~~pilot data are~~ respectively transmitting ~~ted~~ via a plurality of ~~the same pilot~~ sub-carriers, ~~using different symbols,~~ the method comprising:

computing a first correlation value representing ~~acc~~the correlation between ~~ording to~~ a plurality of first signals of a first symbol ~~both a~~ and a plurality of second signals of a second symbol previous to the first symbol, wherein the first and the second signals are both transmitted via the same sub-carriers and the value of the first and the second signals are different~~pilot data transmitted via a pilot sub-carrier using a current symbol and a first comparison data corresponding to a pilot data transmitted via the pilot sub-carrier using a previous symbol~~;

computing a second correlation value representing the correlation between the first signals and a plurality of third signals of a third symbol next to the first symbol, wherein the first and the third signals are both transmitted via the same sub-carriers and the value of the first and the third signals are different ; ~~according to both the pilot data using the current symbol and a second comparison data corresponding to a pilot data transmitted via the pilot sub-carrier using a next symbol;~~

comparing the first correlation value with the second correlation value; and

adjusting the ~~delaying~~ timing of the boundary according to the comparison result. ~~if the first correlation value is greater than the second correlation value, and advancing timing of the boundary if the first correlation value is not greater than the second correlation value.~~

2. The method of claim 1, wherein the signals include a plurality of pilot signals and a plurality of data signals.

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3. The method of claim 2, wherein the corresponding pilot signals of the first, the second, and the third symbols are not the same and the first, the second, and the third signals are all pilot signals. ~~step of computing the first correlation value comprises:~~

4. The method of claim 2, wherein the first, the second, and the third signals are all data signals.

5. The method of claim 4, wherein the corresponding pilot signals of the first, the second, and the third symbols are all the same.

6. The method of claim 1, wherein the step of computing the first correlation value comprises:

computing a conjugated value of ~~ing~~ the first signals~~pilot data transmitted using the current symbol for producing a conjugated pilot data~~;

multiplying each of the conjugated first signals ~~first comparison data~~ by the corresponding one of the second signals ~~conjugated pilot data~~ for generating a product value; and

generating the first correlation value according to the summation of the product value.

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7. The method of claim ~~1~~6, wherein the first correlation value is generated according to the absolute value of the summation of the product value.

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8. The method of claim 6, wherein the first correlation value is generated according

to the square value of the summation of the product value.

9. The method of claim 1, wherein the step of computing the second correlation value comprises:

computing a conjugated value of the first signals;

multiplying each of the conjugated first signals by the corresponding one of the third signals for generating a product value; and

generating the second correlation value according to the summation of the product value.

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10. The method of claim 9, wherein the second correlation value is generated according to the absolute value of the summation of the product value.

11. The method of claim 9, wherein the second correlation value is generated according to the square value of the summation of the product value.

~~conjugating the pilot data transmitted using the current symbol for producing a conjugated pilot data;~~

~~multiplying the second comparison data by the conjugated pilot data for generating a product value; and~~

~~generating the second correlation value according to the product value.~~

~~4~~12. The method of claim 1, wherein method further comprises: ~~when the pilot data transmitted via the same pilot sub-carrier using different symbols have the same value, the method further comprises:~~

~~e~~equalizing and slicing ~~making a decision of the~~~~the pilot~~ second symbol for generating the second signal; and

~~data transmitted using the previous symbol for generating the first comparison data; and~~

equalizing and slicing the third symbol for generating the third signal~~making a decision of the~~~~the pilot data transmitted using the next symbol for generating the second comparison data.~~~~(use data, not pilot. And need a slicer after equalizer)~~.

13. An apparatus of detecting inter-symbol interference (ISI) of a symbol for adjusting a boundary of the symbol utilized by an OFDM system, wherein each symbol includes a plurality of signals respectively transmitting via a plurality of sub-carriers, the apparatus comprising:

a first correlator for computing a first correlation value representing the correlation between a plurality of first signals of a first symbol and a plurality of second signals of a second symbol previous to the first symbol, wherein the first and the second signals are both transmitted via the same sub-carriers and the value of the first and the second signals are different;

a second correlator for computing a second correlation value representing the correlation between the first signals and a plurality of third symbols of a third symbol next to the first symbol, wherein the first and the third signals are both transmitted via the same sub-carriers and the value of the first and the third signals are different;

a comparator for comparing the first correlation value with the second correlation value; and

a timing controller for adjusting the timing of the boundary according to the comparison result.

14. The apparatus of claim 13, wherein the signals include a plurality of pilot signals and a plurality of data signals.

15. The apparatus of claim 13, wherein the corresponding pilot signals of the first, the

second, and the third symbols are not the same and the first, the second, and the third signals are all pilot signals.

16. The apparatus of claim 13, wherein the first, the second, and the third signals are all data signals.

17. The apparatus of claim 16, wherein the corresponding pilot signals of the first, the second, and the third symbols are the same.

18. The apparatus of claim 12, wherein the first correlator further comprises:

a conjugating unit for computing a conjugated value of the first data;

a multiplying unit for multiplying the conjugated first data by the second data for generating a product value; and

a correlation value computer for generating the first correlation value according to the product value.

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19. The apparatus of claim 17, wherein the correlation value computer further comprises:

a absolute value calculating unit for calculating the absolute value of each of the product values; and

a summation unit for calculating the sum of the absolute value of the product values.

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20. The apparatus of claim 17, wherein the correlation value computer further comprises:

a square value calculating unit for calculating the square value of each of the product values; and

a summation unit for calculating the sum of the square value of the product values.

21. The apparatus of claim 13, wherein the second correlator further comprises:

a conjugating unit for computing a conjugated value of the first data;

a multiplying unit for multiplying the conjugated first data by the third data for generating a product value; and

a correlation value computer for generating the second correlation value according to the product value.

22. The apparatus of claim 21, wherein the correlation value computer further comprises:

a absolute value calculating unit for calculating the absolute value of each of the product values; and

a summation unit for calculating the sum of the absolute value of the product values.

23. The apparatus of claim 21, wherein the correlation value computer further comprises:

a square value calculating unit for calculating the square value of each of the product values; and

a summation unit for calculating the sum of the square value of the product values.

24. The apparatus of claim 13, wherein the apparatus further comprises:

a first equalizer for equalizing the second symbol;

a first slicer coupled to the first correlator for slicing the equalized second symbol;

a second equalizer for equalizing the third symbol; and

a second slicer coupled to the second correlator for slicing the equalized second symbol;

~~5. The method of claim 1 wherein when the pilot data respectively transmitted via the~~

~~same pilot sub-carrier using different symbols have known predetermined values, the method further comprises:~~

~~selecting a known pilot data corresponding to the pilot data transmitted using the previous symbol as the first comparison data; and~~

~~selecting a known pilot data corresponding to the pilot data transmitted using the next symbol as the second comparison data.~~

~~6. A method of detecting inter-carrier-symbol interference (ICSI) in an OFDM system for tuning a boundary utilized by the OFDM system, the method comprising:~~

~~computing a first correlation value according to a first data transmitted using a current symbol via a first sub-carrier and a second data transmitted using a previous symbol via a second sub-carrier;~~

~~computing a second correlation value according to the first data transmitted using the current symbol and a third data transmitted using a next symbol by the second sub-carrier;~~

~~comparing the first correlation value with the second correlation value; and~~

~~delaying timing of a boundary of the OFDM system if the first correlation value is greater than the second correlation value, and advancing timing of the boundary of the OFDM system if the first correlation value is not greater than the second correlation value.~~

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~~7.The method of claim 6 wherein the step of computing the first correlation value comprises:~~

~~equalizing and making a decision of the second data transmitted using the previous symbol for generating an equalized decision data;~~

~~conjugating the first data transmitted using the current symbol for generating a conjugated data;~~

~~multiplying the equalized decision data that uses the previous symbol by the conjugated data that uses the current symbol for generating a product value; and~~

~~generating the first correlation value according to the product value.~~

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~~8.The method of claim 6 wherein the step of computing the second correlation value comprises:~~

~~equalizing the third data transmitted using the next symbol for producing an equalized data;~~

~~conjugating the first data transmitted using the current symbol for producing a conjugated data;~~

~~multiplying the equalized data that uses the next symbol by the conjugated data that uses the current symbol for generating a product value; and~~

~~generating the second correlation value according to the product value.(same as claim 7)~~

~~9. An apparatus of detecting inter-symbol interference (ISI) in an OFDM system for tuning a boundary utilized by the OFDM system, wherein a plurality of pilot data are respectively transmitted via the same pilot sub-carrier using different symbols, the apparatus comprising:~~

~~a first correlator for computing a first correlation value according to both a pilot data transmitted using a current symbol via a pilot sub-carrier and a first~~

~~comparison pilot data corresponding to a pilot data transmitted using a previous symbol via the pilot sub-carrier;~~

~~a second correlator for computing a second correlation value according to both the pilot data transmitted using the current symbol and a second comparison pilot data corresponding to a pilot data transmitted using a next symbol via the pilot sub-carrier;~~

~~a comparator connected to the first correlator and the second correlator for generating a control signal; and~~

~~a timing controller connected to the comparator for shifting timing of the boundary according to the control signal, wherein the timing controller delays timing of the boundary if the first correlation value is greater than the second correlation value, and advances timing of the boundary if the first correlation value is not greater than the second correlation value.~~

~~10. The apparatus of claim 9 wherein the first correlator comprises:~~

~~a conjugating unit for generating a conjugated pilot data according to the pilot data transmitted using the current symbol;~~

~~a multiplier connected to the conjugating unit for generating a product value according to the conjugated pilot data and the first comparison data; and~~

~~an absolute value calculating unit connected to the multiplier for generating the first correlation value according to the product value.(or a square value calculating unit)~~

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~~11. The apparatus of claim 9 wherein the second correlator comprises:~~

~~a conjugating unit for generating a conjugated pilot data according to the pilot~~

~~data transmitted using the current symbol;~~

~~a multiplier connected to the conjugating unit for generating a product value according to the conjugated pilot data and the second comparison data; and~~

~~an absolute value calculating unit connected to the multiplier for generating the second correlation value according to the product value. (or a square value calculating unit)~~

~~12. The apparatus of claim 9 wherein when the pilot data respectively transmitted via the same pilot sub-carrier using different symbols have the same value, the detector further comprises:~~

~~an equalizer connected to a multiplier for equalizing the pilot data that uses the previous symbol and generating the first comparison data accordingly; and~~

~~an equalizer connected to a multiplier for equalizing the pilot data that uses the next symbol and generating the second comparison data accordingly.(same as claim 4)~~

~~13.The apparatus of claim 9 wherein the pilot data respectively transmitted via the same pilot sub-carrier using different symbols have known predetermined values.~~

~~14. An apparatus of detecting inter-carrier-symbol interference (ICSI) in an OFDM system for tuning a boundary utilized by the OFDM system, the apparatus comprising:~~

~~a first correlator, for computing a first correlation value according to a first data transmitted using a current symbol via a first sub-carrier and a second data transmitted using a previous symbol via a second sub-carrier;~~

~~a second correlator for computing a next correlation value according to the first data transmitted using the current symbol and a third data transmitted using a next symbol via the second sub-carrier;~~

~~a comparator connected to the first correlator and the second correlator for generating a control signal according to the first and second correlation value; and~~

~~a timing controller connected to the comparator for shifting the timing of a boundary of the OFDM system according to the control signal, wherein the timing controller delays timing of the boundary if the first correlation value is greater than the second correlation value, and advances timing of the boundary if the first correlation value is not greater than the second correlation value.~~

~~15. The apparatus of claim 14 wherein the first correlator comprises:~~

~~a conjugating unit for generating a conjugated data according to the first data transmitted using the current symbol ;~~

~~an equalizer for generating an equalized data according to the second data transmitted using the previous symbol;~~

~~a multiplier connected to the equalizer and the conjugating unit for generating a product value according to the equalized data and the conjugated data; and~~

~~an absolute value calculating unit connected to the multiplier for generating the first correlation value according to the product value.(same as claim 7, 10)~~

~~16.The apparatus of claim 14 wherein the second correlator comprises:~~

~~a conjugating unit for generating a conjugated data according to the first data transmitted using the current symbol ;~~

~~an equalizer for generating an equalized data according to the third data transmitted using the next symbol;~~

~~a multiplier connected to the equalizer and the conjugating unit for generating a product value according to the equalized data and the conjugated data; and~~

~~an absolute value calculating unit connected to the multiplier for generating the second correlation value according to the product value.(same as claim 7, 10)~~

Abstract of Disclosure

A method for detecting inter-symbol interference (ISI) in an OFDM system includes the steps of computing a first correlation value representing the correlation between a plurality of first signals of a first symbol and a plurality of second signals of a second symbol previous to the first symbol, wherein the first and the second signals are both transmitted via the same sub-carriers and the value of the first and the second signals are different; computing a second correlation value representing the correlation between the first signals and a plurality of third signals of a third symbol next to the first symbol, wherein the first and the third signals are both transmitted via the same sub-carriers and the value of the first and the third signals are different ; comparing the first correlation value with the second correlation value; and adjusting the timing of the boundary according to the comparison result. ~~computing a first correlation value according to a pilot data transmitted using a current symbol via a pilot sub-carrier and a first comparison data corresponding to a pilot data transmitted using a previous symbol via the pilot sub-carrier; computing a second correlation value according to the pilot data using the current symbol and a second comparison data corresponding to a pilot data transmitted using a next symbol via the pilot sub-carrier; comparing the first correlation value with the second correlation value;~~

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Figı

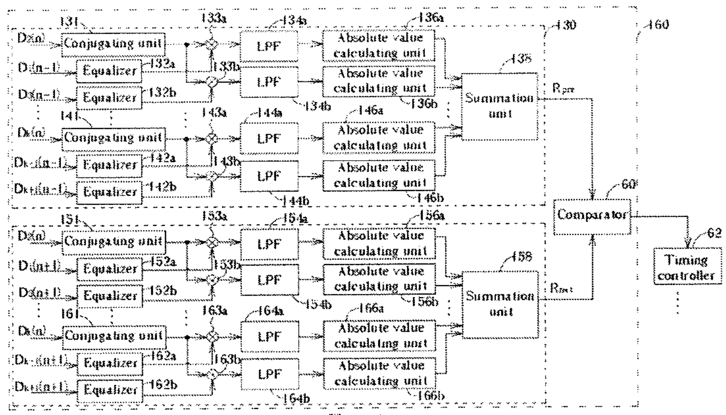

Fig. 4

~~Need a slicer after each Equalizer~~

並設定為第一頁，因此本文起始處的頁數不會變動。

(2) 請於各個段落之間加註意見。加註時請於相關問題發生段落之起始處或是結尾處插入另一段落，加註修正意見之段落請使用紅色字體並於頭尾加上"【修正意見：】"的標記。

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NPO#REA-P0087-USA:0/初稿/金若芸

Title

METHOD AND APPARATUS OF DETECTING ISI/ICSI IN AN OFDM SYSTEM ~~FOR CORRECTLY TUNING A BOUNDARY UTILIZED BY THE OFDM SYSTEM~~

Cross Reference To Related Applications

This is a co-pending Application No. XX/XXXXXX, filed on the same day with the present patent application, entitled "METHOD AND APPARATUS OF DETECTING ISI/ICSI IN AN OFDM SYSTEM" and assigned to the same assignee, the contents of which are incorporated herein by reference.

Background of Invention

1. Field of the Invention

The invention relates to an apparatus for use in an OFDM system and a method thereof ~~and a method of tuning a boundary of an OFDM system~~, and more particularly, to ~~a method and~~ an apparatus for ~~of~~ detecting ISI/ICS~~I~~ in an OFDM system and a method thereof~~for correctly tuning a boundary utilized by the OFDM system~~.

2. Description of the Prior Art

* 在描述 prior art 時，除非是發明人提供的，否則最好不要自己 create 圖。另，對 prior art 的描述不需要太詳細。可以請發明人多提供相關資料 (paper/patent)，以 IDS(information disclosure statement) 方式提出。

~~Generally speaking, m~~Most OFDM transceivers suffer from well-known problems of inter-symbol interference (ISI) and inter-carrier interference (ICI). An additional guard interval (GI) is added between two symbols ~~Therefore, some slices in~~

~~a packet of the OFDM transceiver are reserved for a plurality of guard intervals (GI)~~ to recover ~~reduce the influence of~~ the ISI and the ICI. When receiving a packet including a plurality of symbols, ~~Please refer to Fig.1, which is a schematic diagram of a~~ a conventional ~~prior art~~ OFDM receiver ~~10. As shown in Fig.1, the OFDM receiver 10 comprises a boundary detector 18 for~~ detects ~~ing~~ the ~~a~~ boundary of each symbol,s ~~, a GI remover 15 for~~ removes ~~ing a plurality of~~ GIs of ~~in~~ each symbol according to the detected boundary of the symbol, and then demodulated the symbol through F~~and outputting the data S1, a~~ fast ~~f~~Fourier ~~t~~Transform~~er~~ (FFT) operation. If the~~17 for demodulating the data S1 transmitted via different sub-carriers using each symbol to output the demodulated data S2, and a timing controller 19 for providing timing to the GI remover 15 to triggering the removal of GIs. However, the~~ detected boundary of the symbols is ~~may~~ not ~~be~~ reliable owing to the ~~influence of~~ multi-path effect and other factors, the ISI and ICI problems may still occur.

One conventional ~~prior~~ art applied to improve the precision of boundary detection is to estimate the time shift of the detected boundary according to ~~solve this problem detects~~ the frequency domain linear phase shift of the demodulated data. ~~, S_2, estimates the time shift of the transmitted data S_1 caused by the time shift of the detected boundary according to the FFT theorem, and then shifts the timing of the boundary for a determined distance according to the time shift. That is, the boundary is shifted to a correct position within the packet.~~ Another conventional ~~prior~~ art disclosed is to estimate the time shift of the detected boundary according to the ~~estimates the time shift of the boundary through the~~ channel impulse response of the symbol. H~~, and then shifts the timing of the boundary for a determined distance according to the time shift.~~

——owever,~~Unfortunately,~~ when the delay spread phenomenon is too severe, the ISI and ICI problem cannot be recovered by both of the ~~ose~~ two conventional ~~prior art~~ techniques and the boundary detection –may be ~~cause~~ imprecise which may cause divergence or even failure in receiving when receiving symbols. ~~, which seriously damages the reliability of the OFDM receiver 10. It is because those two prior art techniques adjust the boundary too fast by shifting the boundary by a determined distance. The boundary detector 18 may make a mistake in detecting the required boundary. In other words, an erroneous boundary is detected by the boundary detector 18 when the surrounding environment is full of noise. Therefore, it's difficult to tune the boundary back to a correct position according to the erroneously detected boundary. As a result, the OFDM receiver 10 may malfunction. Furthermore, the tuning range of those two prior art techniques are small. That is to say, the accuracy of boundary detector 18 is required. How to correctly tune the boundary is very important for the OFDM receiver 10 in order to extract the wanted data from the received packet.~~

Summary of Invention

It is therefore one of the objects ~~ives~~ of the claimed invention to provide a method and an apparatus of detecting ISI/ICSI in an OFDM system for use in boundary tracking ~~correctly tuning a boundary~~ utilized by the OFDM system to solve the above-mentioned problem.

According to an embodiment of the claimed invention, a method of detecting inter-carrier-symbol interference (ICSI) of a symbol for adjusting a boundary of the symbol utilized by an OFDM system is disclosed. Each symbol includes a plurality

of signals respectively transmitting via a plurality of sub-carriers. The disclosed method comprises the steps of computing a first correlation value representing the correlation between at least one of first signals of a first symbol and at least one of second signals of a second symbol previous to the first symbol, wherein the at least one first signal is transmitted via a first sub-carrier and the at least one second signal is transmitted via a second sub-carrier adjacent to the first sub-carrier; computing a second correlation value representing the correlation between the at least one first signal and at least one of third signals of a third symbol next to the first symbol, wherein the at least one first signal is transmitted via the first sub-carrier and the at least one third signal is transmitted via the second sub-carrier; comparing the first correlation value with the second correlation value; and adjusting the timing of the boundary according to the comparison result. ~~an ISI detector is disclosed. The ISI detector comprises a first correlator for computing a first correlation value according to a pilot data transmitted using a current symbol via a pilot sub-carrier and a first comparison data corresponding to a pilot data transmitted using a previous symbol via the pilot sub-carrier; a second correlator for computing a second correlation value according to the pilot data transmitted using the current symbol and a second comparison data corresponding to a pilot data transmitted using the next symbol via the pilot sub-carrier; a comparator connected to the first correlator and the second correlator for generating a control signal; and a timing controller connected to the comparator for shifting the timing of a boundary of the OFDM system according to the control signal.~~

According to an embodiment of the claimed invention, an apparatus of detecting inter-carrier-symbol interference (ICSI) of a symbol for adjusting a boundary of the symbol utilized by an OFDM system is disclosed. Each symbol includes a plurality

of signals respectively transmitting via a plurality of sub-carriers. The disclosed apparatus comprises a first correlator for computing a first correlation value representing the correlation between at least one of first signals of a first symbol and at least one of second signals of a second symbol previous to the first symbol, wherein the at least one first signal is transmitted via a first sub-carrier and the at least one second signal is transmitted via a second sub-carrier adjacent to the first sub-carrier; a second correlator for computing a second correlation value representing the correlation between the at least one first signal and at least one of third signals of a third symbol next to the first symbol, wherein at least one first signal is transmitted via the first sub-carrier and the at least one third signal is transmitted via the second sub-carrier; a comparator for comparing the first correlation value with the second correlation value; and a timing controller for adjusting the timing of the boundary according to the comparison result.~~an ICSI detector is disclosed. The ICSI detector comprises a first correlator for computing a first correlation value according to a first data transmitted using a current symbol via a first sub-carrier and a second data transmitted using a previous symbol via a second sub-carrier ; a second correlator for computing a next correlation value according to the first data transmitted using the current symbol and a third data transmitted using a next symbol by the second sub-carrier ; a comparator connected to the first correlator and the second correlator for generating a control signal; and a timing controller connected to the comparator for shifting the timing of a boundary of the OFDM system according to the control signal.~~

Brief Description of Drawings

~~Fig.1 is a schematic diagram of a prior art OFDM receiver.~~

Fig.~~2~~1 is a schematic diagram of an ISI detector according to one embodiment of the

present invention.

Fig.~~3~~2 is a schematic diagram of an ISI detector according to another embodiment of the present invention.

Fig.~~4~~3 is a schematic diagram of an ICSI detector according to an embodiment of the present invention.

Detailed Description

~~In order to solve the problem mentioned above, the primary objective of the invention provides an ISI/ICSI detector and a related method for detecting the source where the interference is introduced. Then, the boundary is shifted away from the source by a very small distance repeatedly, which reduces the influence of ISI/ICSI gradually.~~

Please refer to Fig.~~2~~1, which is a schematic diagram of an ISI detector 20 according to one embodiment of the present invention. As shown in Fig.~~2~~1, the ISI detector 20 is coupled ~~connected~~ (直接連接用 connect，信號連結用 couple，通常電路都用 couple) to a timing controller 62, and the ISI detector 20 comprises two correlators 21, 41 for respectively generating a correlation value R_{pre} and a correlation value R_{nxt} and a comparator 60 to compare both correlation values~~. The correlators 21, 41 are used for respectively generating a correlation value R_{pre} and a correlation value R_{nxt}~~. The correlation value R_{pre} ~~s~~represents ~~tands for~~ the magnitude of the ISI caused by the ~~generated from a~~ previous symbol, and the correlation value R_{nxt} ~~s~~represents ~~tands for~~ the magnitude of the ISI caused by the ~~generated from a~~ next symbol. The comparator 60 is used to compare the correlation value R_{pre} with the correlation value R_{nxt} and generate a control signal Sc according to the comparison result. The timing controller 62 ~~has the same functionality as that of the timing controller 19 shown in~~

~~Fig.1. That is, the timing controller 62 in this preferred embodiment~~ is used to control the timing of a boundary of an OFDM system according to the control signal Sc.

As shown in Fig.~~2~~1, the correlator 21 of this embodiment comprises ~~a plurality of~~ conjugating units 22,……, 32, ~~; a plurality of~~ multipliers 24,……, 34, ~~; a plurality of~~ low-pass filters 25,……, 35, ~~; a plurality of~~ absolute value calculating units 26,……, 36, ~~;~~ and a summation unit 28. The conjugating units 22,……, 32 are used for respectively generating conjugated pilot data $P_1(n)^*$,……, $P_k(n)^*$ by conjugating corresponding pilot data $P_1(n)$,……, $P_k(n)$ that was transmitted using ~~a~~the current symbol. The multipliers 24,……, 34 are used for respectively generating product values by multiplying those conjugated pilot data $P_1(n)^*$, $P_k(n)^*$ with a corresponding comparison data $\hat{P}_1(n-1)$,…… $\hat{P}_k(n-1)$ that was transmitted using ~~a~~the previous symbol. The low-pass filters 25,……, 35 are used for averaging the product values outputted from these multipliers 24, 34, respectively. The absolute value calculating units 26,……, 36 are used for generating absolute values of the average values corresponding to the product values. The summation unit 28 is used for generating a correlation value R_{pre} by summing these absolute values.

Similarly, the correlator 41 comprises ~~a plurality of~~ conjugating units 42,……, 52, ~~; a plurality of~~ multipliers 44,……, 54, ~~; a plurality of~~ low-pass filters 45,……, 55, ~~; a plurality of~~ absolute value calculating units 46,……, 56, ~~;~~ and a summation unit 48. The conjugating units 42,……, 52 are used for respectively generating conjugated pilot data $P_1(n)^*$,……, $P_k(n)^*$ by conjugating corresponding pilot data $P_1(n)$, $P_k(n)$ that was transmitted using a current symbol. The multipliers 44,……, 54 are used for respectively generating product values by multiplying those conjugated pilot data $P_1(n)^*$,……, $P_k(n)^*$ with a corresponding comparison data $\hat{P}_1(n+1)$,……

$\hat{P}_k(n+1)$ that was transmitted using ~~a~~the next symbol. The low-pass filters 45, ... 55 are used for averaging the product values outputted from these multipliers 44, 54, respectively. The absolute value calculating units 46, ... 56 are used for generating absolute values of the average values corresponding to the product values outputted from these multipliers 44, 54. The summation unit 48 is used for generating a correlation value R_{nxt} by summing these absolute values.

According to the well-known theorem of correlation, the following Equations (1) and (2) are used to better explain operations of the correlators 21, 41.

$$R_{pre} = \sum_{k=1}^{K} abs(E[\hat{P}_k(n-1) \cdot P_k(n)^*]) \qquad \text{Equation (1)}$$

$$R_{nxt} = \sum_{k=1}^{K} abs(E[\hat{P}_k(n+1) \cdot P_k(n)^*]) \qquad \text{Equation (2)}$$

$P_k(n)^*$ denotes the conjugated pilot data transmitted using an n^{th} symbol via the a k^{th} sub-carrier, $\hat{P}_k(n-1)$ denotes the comparison data transmitted using an $(n-1)^{th}$ symbol via a k^{th} sub-carrier, and $\hat{P}_k(n+1)$ denotes another comparison data transmitted using an $(n+1)^{th}$ symbol via a k^{th} sub-carrier. Please note that the more sub-carriers that are considered, the more reliable result will be generated.

This embodiment of ISI detector is for use ~~I~~in the ~~some~~ OFDM system that ~~s,~~ the pilot ~~data~~ of different symbols transmitted via the same pilot sub-carrier ~~using different symbols~~ have known but different predetermined values. In this embodiment, ~~Therefore,~~ $\hat{P}_k(n-1)$ and $\hat{P}_k(n+1)$ ~~in the above embodiment~~ denote those known predetermined values of pilot ~~data~~. Since the pilots of two different symbols are different, the correlation between pilot of different symbols is due to the interference between these two symbols. Therefore, ~~I~~if the correlation value R_{pre} is greater than

the correlation value R_{nxt}, it means that the interference is mainly introduced from using the previous symbol, which ~~; this~~ is due to ~~the fact that~~ the timing of the ~~actual~~detected boundary is ahead of ~~leads~~ that of the ideal boundary. In this manner, ~~Therefore, the comparator 60 outputs the control signal Sc to~~ the timing controller 62 ~~for~~ delays ~~ing~~ the timing of the ~~actual~~ boundary according to the control signal Sc outputted from the comparator 60. On the other_hand, if the correlation value R_{pre} is less than the correlation value R_{nxt}, it means that the interference is mainly introduced from using the following symbol, which ~~; this~~ is due to ~~the fact that~~ the timing of the ~~actual~~ detected boundary lags behind that of the ideal boundary. In this manner, ~~Therefore,~~ the comparator 60 outputs the control signal Sc to the timing controller 62 for advancing the timing of the ~~actual~~ boundary. As a result, the ISI effect is alleviated.

Please refer to Fig.~~3~~2, which is a schematic diagram of an ISI detector 80 according to another embodiment of the present invention. As show in Fig.~~3~~2, the ISI detector 80 comprises two correlators 90, 110 and a comparator 120. The correlators 90, 110 are used for generating correlation values R_{pre} and R_{nxt}, respectively. The comparator 120 compares the correlation value R_{pre} with the correlation value R_{nxt} for outputting a control signal Sc to control the timing controller 129.

In some OFDM systems, the pilot data of different symbols transmitted via the same pilot sub-carrier have known and the same values. This embodiment of ISI detector 80 shown in Fig. 2 is for use in this kind of OFDM system. In this embodiment, k sub-carriers for transmitting data are chosen through decision directed method for determining ISI. Since the data of two different symbols transmitted via the same sub-carrier are different, the correlation between the data of different

symbols is due to the interference between these two symbols.

In this ~~preferred~~ embodiment, the correlator 90 has 1st ~~a plurality of~~ delay circuits 91a, ~~91b,~~ ……, 101a, 2nd delay circuits 91b, ……, 101b ~~101b,~~ ~~; a plurality of~~ conjugating units 92, ……, 102, ~~; a plurality of~~ multipliers 93, ……, 103, ~~; a plurality of~~ equalizers 94, ……, 104, ~~; a plurality of~~ slicers (對應的標號) ~~(equalizer 後還需要加一個 slicer，表示對 data 做 decision)~~, ~~; a plurality of~~ low-pass filters 95, ……, 105, ~~; a plurality of~~ absolute value calculating units 96, ……, 106, ~~;~~ and a summation unit 98. Concerning the other correlator 110, it has 1st ~~a plurality of~~ delay circuits 111, ……, 121, ~~; a plurality of~~ conjugating units 112, ……, 122, ~~; a plurality of~~ multipliers 113, ……, 123, ~~; a plurality of~~ equalizers 114, ……, 124, slicers (對應的標號), ~~; a plurality of~~ low-pass filters 115, ……, 125, ~~; a plurality of~~ absolute value calculating units 116, ……, 126, ~~;~~ and a summation unit 128. Please note that the components shown in Figs. ~~2~~1 and ~~3~~2 that have the same name have substantially the same ~~identical~~ (通常不會用 identical 這麼強烈的詞，都是用 substantially the same) functionality and operation. The related description, therefore, is not repeated for simplicity.

~~The major difference between the correlators 90, 110 shown in Fig.3 and the correlators 21, 41 shown in Fig.2 is the configuration of the delay circuits 91a, 91b, 101a, 101b and the equalizers 94, 104, 114, 124.~~

For an OFDM system having pilot ~~data~~ transmitted via the same pilot sub-carrier using different symbols corresponding to the same ~~an identical~~ value, the ISI detector 80 is preferably utilized. As shown in Fig. ~~3~~2, the comparison data $\hat{Q}_1(n-1)$ and

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$\hat{Q}_k(n-1)$ are the decision results from received data signal ~~generated by equalizing the pilot data~~ Q_1(n-1) and Q_k(n-1) through the corresponding equalizers 94,~~,~~ ~~and~~ ……,104~~;~~, and the slicers (標號)~~;~~, wherein the ~~pilot~~ data Q_1(n-1),……, ~~and~~ Q_k(n-1) are delayed ~~and transmitted to the equalizers 94 and 104~~ by the corresponding 1st delay circuits 91a,……~~,91b,~~,101a, 2nd delat circuits 91b,……,101b and then transmitted to the equalizers 94,……,104. Regarding the comparison data $\hat{Q}_1(n+1)$ and $\hat{Q}_k(n+1)$, they are generated by directly equalizing and slicing the ~~pilot~~ data Q_1(n+1) and Q_k(n+1) with the corresponding equalizers 114,……,~~and~~ 124 and slicers (標號).

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It should be noted that the symbol Q(.) represents the received data signal of the corresponding ~~為 d~~data sub-carrier and the symbol $\hat{Q}$ (.) represents the result of equalizing and slicing of the data signal ~~;received data signal，Q hat(.)為~~ of Q(.) ~~經過 Equalizer、Slicer 後 decision 的結果. 。~~

With the circuit configuration shown in Fig.~~3~~2, the correlation values R_{pre} and R_{nxt} are computed according to the following equations (3) and (4).

$$R_{pre} = \sum_{k=1}^{K} abs(E[\hat{Q}_k(n-1) \cdot Q_k(n)^*]) \qquad \text{Equation (3)}$$

$$R_{nxt} = \sum_{k=1}^{K} abs(E[\hat{Q}_k(n+1) \cdot Q_k(n)^*]) \qquad \text{Equation (4)}$$

$Q_k(n)^*$ denotes the conjugated ~~pilot~~ data transmitted using an n^{th} symbol via the a k^{th} sub-carrier, $\hat{Q}_k(n-1)$ denotes the equalized comparison data transmitted using an $(n-1)^{th}$ symbol via a k^{th} sub-carrier, and $\hat{Q}_k(n+1)$ denotes another equalized comparison data transmitted using an $(n+1)^{th}$ symbol via a k^{th} sub-carrier.

Therefore, if the correlation value R_{pre} is greater than the correlation value R_{nxt}, it means that the interference is mainly caused by the previous symbol, in this manner, the timing of the boundary is delayed by ~~a small amount of time several times through~~ the timing controller 114. If the correlation value R_{pre} is smaller than the correlation value R_{nxt}, it means that the interference is mainly caused by the next symbol, in this manner, ~~; otherwise,~~ the timing is advanced by ~~a small amount of time several times through~~ the timing controller 114. In the end, the ISI effect is alleviated.

It is well-known that the ISI might be introduced by adjacent sub-carriers as well. That is, inter-carrier-symbol-interference (ICSI) occurs. Please refer to Fig.4~~3~~, which is a schematic diagram of an ICSI detector 160 according to the third ~~an~~ embodiment of the present invention. In this embodiment, k sub-carriers of the different symbols for transmitting data are chosen through decision directed method for determining ISI. Since the data of two different sub-carriers are different, the correlation between the data of different sub-carriers is due to the interference between these two sub-carriers.

The ICSI detector 160 has two correlators 130, 150 and a comparator 170. The correlator 130 includes ~~a plurality of~~ conjugating units 131,……, 141, ~~; a plurality of~~ equalizers 132a, ~~-~~132b,……, 142a, 142b, ~~; a plurality of~~ slicers ~~(equalizer 後還需要加一個 slicer，表示對 data 做 decision(標號)~~, ~~; a plurality of~~ multipliers 133a, 133b,……, 143a, 143b, ~~; a plurality of~~ low-pass filters 134a, 134b,……, 144a, 144b, ~~; a plurality of~~ absolute value calculating units 136a, 136b,……, 146a, 146b, ~~;~~ and a summation unit 138. Similarly, the correlator 150 includes ~~a plurality of~~ conjugating units 151,……, 161, ~~; a plurality of~~ equalizers 152a, 152b,……, 162a, 162b, slicers (標號), ~~; a plurality of~~ multipliers 153a, 153b,……, 163a, 163b, ~~; a plurality of~~ low-pass filters 154a, 154b,……, 164a, 164b, ~~; a plurality of~~ absolute value

calculating units 156a, 156b, ..., 166a, 166b, ~~;~~ and a summation unit 158.

I t is obvious that the correlators 130, 150 have ~~the~~ substantially the same circuit architecture. However, the data inputted into the correlators 130, 140 are different. Please note that the components shown in Figs.~~2~~1, ~~3~~2, and ~~4~~3 that have the same name have substantially the same ~~identical~~ functionality and operation. The related description, therefore, is not repeated for simplicity. The following equations (5) and (6) are used to better explain operations of the correlators 130 and 150.

$$R_{pre} = \sum_{k=1}^{K} \left(abs(E[\hat{D}_{k-1}(n-1) \cdot D_k(n)^*]) + abs(E[\hat{D}_{k+1}(n-1) \cdot D_k(n)^*]) \right)$$

Equation (5)

$D_k(n)^*$ represents the conjugate of data $D_k(n)$ transmitted using an n^{th} symbol via a k^{th} sub-carrier, $\hat{D}_{k-1}(n-1)$ denotes ~~an equalized~~ a decision result of data $D_{k-1}(n-1)$ transmitted using an $(n-1)^{th}$ symbol via a $(k-1)^{th}$ sub-carrier, and $\hat{D}_{k+1}(n-1)$ denotes ~~an equalized~~ a decision result of data $D_{k+1}(n-1)$ transmitted using an $(n-1)^{th}$ symbol via a $(k+1)^{th}$ sub-carrier. As a result, the correlation value R_{pre} is computed to estimate the magnitude of ICSI imposed upon the data $D_k(n)$. That is, the ICSI generated from the adjacent $(k-1)^{th}$ sub-carrier and $(k+1)^{th}$ sub-carrier using a previous symbol is calculated according to the above Equation (5).

$$R_{nxt} = \sum_{k=1}^{K} \left(abs(E[\hat{D}_{k-1}(n+1) \cdot D_k(n)^*]) + abs(E[\hat{D}_{k+1}(n+1) \cdot D_k(n)^*]) \right)$$

Equation (6)

$D_k(n)^*$ represents the conjugate of data $D_k(n)$ transmitted using an n^{th} symbol via a k^{th} sub-carrier, $\hat{D}_{k-1}(n+1)$ denotes ~~an equalized~~a decision result of data $D_{k-1}(n+1)$ transmitted using an $(n+1)^{th}$ symbol via a $(k-1)^{th}$ sub-carrier, and $\hat{D}_{k+1}(n+1)$ denotes ~~an equalized~~a decision result of data $D_{k+1}(n+1)$ transmitted using an $(n+1)^{th}$ symbol via a $(k+1)^{th}$ sub-carrier. It is clear that the correlation value R_{nxt} is also computed to estimate the magnitude of ICSI imposed upon the data $D_k(n)$. In other words, the ICSI generated from the adjacent $(k-1)^{th}$ sub-carrier and $(k+1)^{th}$ sub-carrier using a following symbol is calculated according to the above Equation (6). Please note that data processed by correlators 130 and 150 are transmitted via data sub-carriers not pilot sub-carriers. Finally, the comparator 170 shown in Fig.43 compares the correlation value R_{pre} with the correlation value R_{nxt} for searching a greater one. If the correlation value R_{pre} is greater than the correlation value R_{nxt}, it means that the interference is mainly caused by the previous symbol, in this manner, the timing of the boundary would be delayed by ~~a small amount of time several times through~~ the timing controller 172. If the correlation value R_{pre} is smaller than the correlation value R_{nxt}, it means that the interference is mainly caused by the next symbol, in this manner, ~~; otherwise,~~ the timing of the boundary of the OFDM system would be advanced by the timing controller 172~~a small amount of time several times~~. Therefore, the ICSI effect is alleviated.

In the above embodiments, please note the absolute values are directly summed to generate the wanted correlation values R_{pre} and R_{nxt}. However, the correlation values R_{pre} and R_{nxt} can be generated by using square values instead of the absolute values. For instance, each of the product values is squared before the summation value is calculated. That is, the above Equations (1)-(6) are replaced with the following equations, respectively.

$$R_{pre} = \sum_{k=1}^{K}(E[\hat{P}_k(n-1)\cdot P_k(n)^*])^2 \qquad \text{Equation (1.1)}$$

$$R_{nxt} = \sum_{k=1}^{K}(E[\hat{P}_k(n+1)\cdot P_k(n)^*])^2 \qquad \text{Equation (2.1)}$$

$$R_{pre} = \sum_{k=1}^{K}(E[\hat{Q}_k(n-1)\cdot Q_k(n)^*])^2 \qquad \text{Equation (3.1)}$$

$$R_{nxt} = \sum_{k=1}^{K}(E[\hat{Q}_k(n+1)\cdot Q_k(n)^*])^2 \qquad \text{Equation (4.1)}$$

$$R_{pre} = \sum_{k=1}^{K}\left((E[\hat{D}_{k-1}(n-1)\cdot D_k(n)^*])^2 + (E[\hat{D}_{k+1}(n-1)\cdot D_k(n)^*])^2\right) \qquad \text{Equation (5.1)}$$

$$R_{nxt} = \sum_{k=1}^{K}\left((E[\hat{D}_{k-1}(n+1)\cdot D_k(n)^*])^2 + (E[\hat{D}_{k+1}(n+1)\cdot D_k(n)^*])^2\right) \qquad \text{Equation (6.1)}$$

~~In contrast to the prior art, t~~The method and related device disclosed in the embodiments of the present invention for ~~of~~ detecting ISI/ICSI in an OFDM system for adjusting ~~tuning~~ a boundary of the OFDM system ~~according to the present invention~~ first computes correlation values to predict the source of the ISI/ICSI ~~,~~ and then adjusting the boundary ~~A~~after the source of the ISI/ICSI is determined~~, the boundary is tuned gradually and precisely~~. Therefore, the performance of tracking the boundary of ~~for~~ the OFDM system is greatly improved.

Those skilled in the art will readily observe that numerous modifications and alterations of the device and method may be made while retaining the teachings of the invention. Accordingly, the above disclosure should be construed as limited only by the metes and bounds of the appended claims.

CUST#93A-023
NPO#REA-P0087-USA:0/初稿/金若芸

Claims

1. A method of detecting inter-carrier-symbol interference (ICSI) of a symbol ~~in an OFDM system~~ for adjusting ~~tuning~~ a boundary of the symbol utilized by an ~~the~~ OFDM system, wherein each symbol includes a plurality of signals ~~pilot data are~~ respectively transmitting~~ted~~ via a plurality of ~~the same pilot~~ sub-carriers, ~~using different symbols,~~ the method comprising:

computing a first correlation value representing ~~acc~~the correlation between ~~ording to~~ at least one of first signals of a first symbol ~~both a~~ and at least one of second signals of a second symbol previous to the first symbol, wherein the at least one first signal is transmitted via a first sub-carrier and the at least one second signal is transmitted via a second sub-carrier adjacent to the first sub-carrier~~pilot data transmitted via a pilot sub-carrier using a current symbol and a first comparison data corresponding to a pilot data transmitted via the pilot sub-carrier using a previous symbol~~;

computing a second correlation value representing the correlation between the at least one first signal and at least one of third signals of a third symbol next to the first symbol, wherein the at least one first signal is transmitted via the first sub-carrier and the at least one third signal is transmitted via the second sub-carrier; ~~according to both the pilot data using the current symbol and a second comparison data corresponding to a pilot data transmitted via the pilot sub-carrier using a next symbol;~~

comparing the first correlation value with the second correlation value; and

adjusting the ~~delaying~~ timing of the boundary according to the comparison result. ~~if the first correlation value is greater than the second correlation value, and~~

~~advancing timing of the boundary if the first correlation value is not greater than the second correlation value.~~

2. The method of claim 1, wherein the signals include a plurality of pilot signals and a plurality of data signals.

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3. The method of claim 2, wherein the corresponding pilot signals of the first, the second, and the third symbols are not the same and the at least one first, second, and third signals are all pilot signals. ~~step of computing the first correlation value comprises:~~

4. The method of claim 2, wherein the at least one first, second, and third signals are all data signals.

5. The method of claim 4, wherein the corresponding pilot signals of the first, the second, and the third symbols are all the same.

6. The method of claim 1, wherein the step of computing the first correlation value comprises:

computing a conjugated value of ~~ing~~ the at least one first signal~~pilot data transmitted using the current symbol for producing a conjugated pilot data~~;

multiplying the conjugated at least one first signals ~~first comparison data~~ by the corresponding one of the second signals ~~conjugated pilot data~~ for generating a product value; and

generating the first correlation value according to the summation of the product value.

格式化: 項目符號及編號

7. The method of claim ~~1~~6, wherein the first correlation value is generated according

to the absolute value of the summation of the product value.

8. The method of claim 6, wherein the first correlation value is generated according to the square value of the summation of the product value.

格式化: 項目符號及編號

9. The method of claim 1, wherein the step of computing the second correlation value comprises:

computing a conjugated value of the at least one first signal;

multiplying the conjugated at least one first signal by the corresponding one of the third signals for generating a product value; and

generating the second correlation value according to the summation of the product value.

格式化: 項目符號及編號

10. The method of claim 9, wherein the second correlation value is generated according to the absolute value of the summation of the product value.

11. The method of claim 9, wherein the second correlation value is generated according to the square value of the summation of the product value.

~~conjugating the pilot data transmitted using the current symbol for producing a conjugated pilot data;~~

~~multiplying the second comparison data by the conjugated pilot data for generating a product value; and~~

~~generating the second correlation value according to the product value.~~

412. The method of claim 1, wherein method further comprises: ~~when the pilot data transmitted via the same pilot sub-carrier using different symbols have the same value, the method further comprises:~~

~~e~~equalizing and slicing ~~making a decision of the~~~~the pilot~~ second symbol for generating the at least one second signal; and

~~data transmitted using the previous symbol for generating the first comparison data; and~~

equalizing and slicing the third symbol for generating the at least one third signal~~making a decision of thethe pilot data transmitted using the next symbol for generating the second comparison data.(use data, not pilot. And need a slicer after equalizer).~~

13. An apparatus of detecting inter-carrier-symbol interference (ICSI) of a symbol for adjusting a boundary of the symbol utilized by an OFDM system, wherein each symbol includes a plurality of signals respectively transmitting via a plurality of sub-carriers, the apparatus comprising:

a first correlator for computing a first correlation value representing the correlation between at least one of first signals of a first symbol and at least one of second signals of a second symbol previous to the first symbol, wherein the at least one first signal is transmitted via a first sub-carrier and the at least one second signal is transmitted via a second sub-carrier adjacent to the first sub-carriers;

a second correlator for computing a second correlation value representing the correlation between the at least one first signal and at least one of third signals of a third symbol next to the first symbol, wherein the at least one first signal is transmitted via the first sub-carrier and the at least one third signal is transmitted via the second sub-carrier;

a comparator for comparing the first correlation value with the second correlation value; and

a timing controller for adjusting the timing of the boundary according to the comparison result.

14. The apparatus of claim 13, wherein the signals include a plurality of pilot signals and a plurality of data signals.

15. The apparatus of claim 13, wherein the corresponding pilot signals of the first, the second, and the third symbols are not the same and the at least one first, second, and third signals are all pilot signals.

16. The apparatus of claim 13, wherein the at least one first, second, and third signals are all data signals.

17. The apparatus of claim 16, wherein the corresponding pilot signals of the first, the second, and the third symbols are the same.

18. The apparatus of claim 12, wherein the first correlator further comprises:

a conjugating unit for computing a conjugated value of the at least one first data;

a multiplying unit for multiplying the conjugated at least one first data by the at least one second data for generating a product value; and

a correlation value computer for generating the first correlation value according to the product value.

格式化: 項目符號及編號

19. The apparatus of claim 17, wherein the correlation value computer further comprises:

a absolute value calculating unit for calculating the absolute value of each of the product values; and

a summation unit for calculating the sum of the absolute value of the product values.

格式化: 項目符號及編號

20. The apparatus of claim 17, wherein the correlation value computer further comprises:

a square value calculating unit for calculating the square value of each of the

product values; and

a summation unit for calculating the sum of the square value of the product values.

21. The apparatus of claim 13, wherein the second correlator further comprises:

a conjugating unit for computing a conjugated value of the at least one first data;

a multiplying unit for multiplying the conjugated at least one first data by the at least one third data for generating a product value; and

a correlation value computer for generating the second correlation value according to the product value.

22. The apparatus of claim 21, wherein the correlation value computer further comprises:

a absolute value calculating unit for calculating the absolute value of each of the product values; and

a summation unit for calculating the sum of the absolute value of the product values.

23. The apparatus of claim 21, wherein the correlation value computer further comprises:

a square value calculating unit for calculating the square value of each of the product values; and

a summation unit for calculating the sum of the square value of the product values.

24. The apparatus of claim 13, wherein the apparatus further comprises:

a first equalizer for equalizing the second symbol;

a first slicer coupled to the first correlator for slicing the equalized second symbol;

a second equalizer for equalizing the third symbol; and

a second slicer coupled to the second correlator for slicing the equalized second symbol;

~~5. The method of claim 1 wherein when the pilot data respectively transmitted via the same pilot sub-carrier using different symbols have known predetermined values, the method further comprises:~~

~~selecting a known pilot data corresponding to the pilot data transmitted using the previous symbol as the first comparison data; and~~

~~selecting a known pilot data corresponding to the pilot data transmitted using the next symbol as the second comparison data.~~

~~6. A method of detecting inter-carrier-symbol interference (ICSI) in an OFDM system for tuning a boundary utilized by the OFDM system, the method comprising:~~

~~computing a first correlation value according to a first data transmitted using a current symbol via a first sub-carrier and a second data transmitted using a previous symbol via a second sub-carrier;~~

~~computing a second correlation value according to the first data transmitted using the current symbol and a third data transmitted using a next symbol by the second sub-carrier;~~

~~comparing the first correlation value with the second correlation value; and~~

~~delaying timing of a boundary of the OFDM system if the first correlation value is greater than the second correlation value, and advancing timing of the boundary of the OFDM system if the first correlation value is not greater than the second correlation value.~~

格式化: 項目符號及編號

~~7.The method of claim 6 wherein the step of computing the first correlation value comprises:~~

~~equalizing and making a decision of the second data transmitted using the previous symbol for generating an equalized decision data;~~

~~conjugating the first data transmitted using the current symbol for generating a conjugated data;~~

~~multiplying the equalized decision data that uses the previous symbol by the conjugated data that uses the current symbol for generating a product value; and~~

~~generating the first correlation value according to the product value.~~

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~~8.The method of claim 6 wherein the step of computing the second correlation value comprises:~~

~~equalizing the third data transmitted using the next symbol for producing an equalized data;~~

~~conjugating the first data transmitted using the current symbol for producing a conjugated data;~~

~~multiplying the equalized data that uses the next symbol by the conjugated data that uses the current symbol for generating a product value; and~~

~~generating the second correlation value according to the product value.(same as claim 7)~~

~~9. An apparatus of detecting inter-symbol interference (ISI) in an OFDM system for tuning a boundary utilized by the OFDM system, wherein a plurality of pilot data~~

~~are respectively transmitted via the same pilot sub-carrier using different symbols, the apparatus comprising:~~

~~a first correlator for computing a first correlation value according to both a pilot data transmitted using a current symbol via a pilot sub-carrier and a first comparison pilot data corresponding to a pilot data transmitted using a previous symbol via the pilot sub-carrier;~~

~~a second correlator for computing a second correlation value according to both the pilot data transmitted using the current symbol and a second comparison pilot data corresponding to a pilot data transmitted using a next symbol via the pilot sub-carrier;~~

~~a comparator connected to the first correlator and the second correlator for generating a control signal; and~~

~~a timing controller connected to the comparator for shifting timing of the boundary according to the control signal, wherein the timing controller delays timing of the boundary if the first correlation value is greater than the second correlation value, and advances timing of the boundary if the first correlation value is not greater than the second correlation value.~~

~~10. The apparatus of claim 9 wherein the first correlator comprises:~~

~~a conjugating unit for generating a conjugated pilot data according to the pilot data transmitted using the current symbol;~~

~~a multiplier connected to the conjugating unit for generating a product value according to the conjugated pilot data and the first comparison data; and~~

~~an absolute value calculating unit connected to the multiplier for generating the first correlation value according to the product value.(or a square value~~

~~calculating unit)~~

格式化: 項目符號及編號

~~11.The apparatus of claim 9 wherein the second correlator comprises:~~

~~a conjugating unit for generating a conjugated pilot data according to the pilot data transmitted using the current symbol;~~

~~a multiplier connected to the conjugating unit for generating a product value according to the conjugated pilot data and the second comparison data; and~~

~~an absolute value calculating unit connected to the multiplier for generating the second correlation value according to the product value. (or a square value calculating unit)~~

~~12. The apparatus of claim 9 wherein when the pilot data respectively transmitted via the same pilot sub-carrier using different symbols have the same value, the detector further comprises:~~

~~an equalizer connected to a multiplier for equalizing the pilot data that uses the previous symbol and generating the first comparison data accordingly; and~~

~~an equalizer connected to a multiplier for equalizing the pilot data that uses the next symbol and generating the second comparison data accordingly.(same as claim 4)~~

~~13.The apparatus of claim 9 wherein the pilot data respectively transmitted via the same pilot sub-carrier using different symbols have known predetermined values.~~

~~14. An apparatus of detecting inter-carrier-symbol interference (ICSI) in an OFDM system for tuning a boundary utilized by the OFDM system, the apparatus~~

~~comprising:~~

~~a first correlator, for computing a first correlation value according to a first data transmitted using a current symbol via a first sub-carrier and a second data transmitted using a previous symbol via a second sub-carrier;~~

~~a second correlator for computing a next correlation value according to the first data transmitted using the current symbol and a third data transmitted using a next symbol via the second sub-carrier;~~

~~a comparator connected to the first correlator and the second correlator for generating a control signal according to the first and second correlation value; and~~

~~a timing controller connected to the comparator for shifting the timing of a boundary of the OFDM system according to the control signal, wherein the timing controller delays timing of the boundary if the first correlation value is greater than the second correlation value, and advances timing of the boundary if the first correlation value is not greater than the second correlation value.~~

~~15. The apparatus of claim 14 wherein the first correlator comprises:~~

~~a conjugating unit for generating a conjugated data according to the first data transmitted using the current symbol ;~~

~~an equalizer for generating an equalized data according to the second data transmitted using the previous symbol;~~

~~a multiplier connected to the equalizer and the conjugating unit for generating a product value according to the equalized data and the conjugated data; and~~

~~an absolute value calculating unit connected to the multiplier for generating the first correlation value according to the product value.~~~~(same as claim 7, 10)~~

~~16.The apparatus of claim 14 wherein the second correlator comprises:~~

~~a conjugating unit for generating a conjugated data according to the first data transmitted using the current symbol ;~~

~~an equalizer for generating an equalized data according to the third data transmitted using the next symbol;~~

~~a multiplier connected to the equalizer and the conjugating unit for generating a product value according to the equalized data and the conjugated data; and~~

~~an absolute value calculating unit connected to the multiplier for generating the second correlation value according to the product value.(same as claim 7, 10)~~

Abstract of Disclosure

A method for detecting inter-carrier-symbol interference (ICSI) in an OFDM system includes the steps of computing a first correlation value representing the correlation between at least one of first signals of a first symbol and at least one of second signals of a second symbol previous to the first symbol, wherein the at least one first signal is transmitted via a first sub-carrier and the at least one second signal is transmitted via a second sub-carrier adjacent to the first sub-carrier; computing a second correlation value representing the correlation between the at least one first signal and at least one of third signals of a third symbol next to the first symbol, wherein the at least one first signal is transmitted via the first sub-carrier and the at least one third signal is transmitted via the second sub-carrier; comparing the first correlation value with the second correlation value; and adjusting the timing of the boundary according to the comparison result. ~~computing a first correlation value according to a pilot data transmitted using a current symbol via a pilot sub-carrier and~~

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Figu

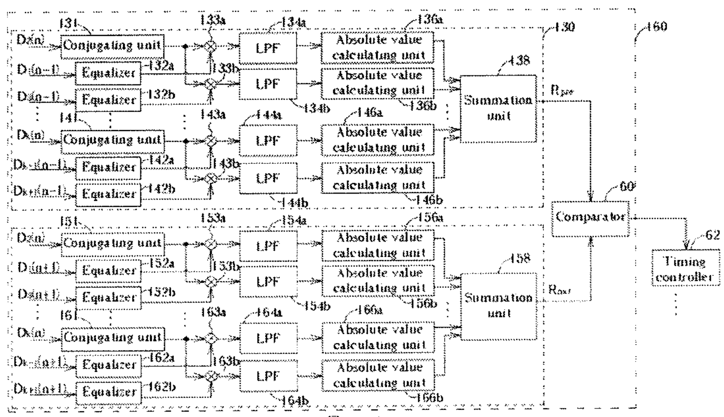

Fig. 4

~~Need a slicer after each Equalizer~~

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Exhibit J

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【修正意見：　】

Title

METHOD AND APPARATUS OF DETECTING ISI/ICSI IN AN OFDM SYSTEM

Cross Reference To Related Applications

This is a co-pending Application No. XX/XXXXXX, filed on the same day with the present patent application, entitled "METHOD AND APPARATUS OF DETECTING ISI/ICSI IN AN OFDM SYSTEM" and assigned to the same assignee, the contents of which are incorporated herein by reference.

Background of Invention

1. Field of the Invention

The invention relates to an apparatus for use in an OFDM system and a method thereof , and more particularly, to an apparatus for detecting ISI/ICSI in an OFDM system and a method thereof.

2. Description of the Prior Art

Most OFDM transceivers suffer from well-known problems of inter-symbol interference (ISI) and inter-carrier interference (ICI). An additional guard interval (GI) is added between two symbols to recover the ISI and the ICI. When receiving a packet including a plurality of symbols, a conventional OFDM receiver detects the boundary of each symbol, removes GI of each symbol according to the detected boundary of the symbol, and then demodulated the symbol through Fast Fourier Transform (FFT) operation. ~~If~~ However the detected boundary may not be reliable owing to the influence of multi-path and other factors.

One conventional art applied to improve the precision of boundary detection is to estimate the time shift of the detected boundary according to the frequency domain linear phase shift of the demodulated data. Another conventional art disclosed is to estimate the time shift of the detected boundary according to the channel impulse response of the symbol. However, when the delay spread phenomenon is too severe, the ISI and ICI problem cannot be recovered by both of the two conventional techniques and the boundary detection may be imprecise which may cause divergence or even failure in receiving when receiving symbols.

Summary of Invention

It is therefore an objective of the claimed invention to provide a method and

apparatus of detecting ISI/ICSI in an OFDM system to solve the above-mentioned problem.

According to the claimed invention, a method of detecting inter-carrier-symbol interference (ICSI) of a symbol for adjusting a boundary of the symbol utilized by an OFDM system is disclosed, wherein each symbol includes a plurality of signals respectively transmitting via a plurality of sub-carriers, the method comprising: computing a first correlation value representing the correlation between at least one of first signals of a first symbol and at least one of second signals of a second symbol previous to the first symbol, wherein the at least one first signal is transmitted via a first sub-carrier and the at least one second signal is transmitted via a second sub-carrier adjacent to the first sub-carrier; computing a second correlation value representing the correlation between the at least one first signal and at least one of third signals of a third symbol next to the first symbol, wherein the at least one first signal is transmitted via the first sub-carrier and the at least one third signal is transmitted via the second sub-carrier; comparing the first correlation value with the second correlation value; and adjusting the timing of the boundary according to the comparison result.

According to the claimed invention, an apparatus of detecting inter-carrier-symbol interference (ICSI) of a symbol for adjusting a boundary of the symbol utilized by an OFDM system is disclosed, wherein each symbol includes a plurality of signals respectively transmitting via a plurality of sub-carriers, the apparatus comprising: a first correlator for computing a first correlation value representing the correlation between at least one of first signals of a first symbol and at least one of second signals of a second symbol previous to the first symbol, wherein the at least one first signal is transmitted via a first sub-carrier and the at least one second signal is transmitted via a second sub-carrier adjacent to the first sub-carriers;

a second correlator for computing a second correlation value representing the correlation between the at least one first signal and at least one of third signals of a third symbol next to the first symbol, wherein the at least one first signal is transmitted via the first sub-carrier and the at least one third signal is transmitted via the second sub-carrier; a comparator for comparing the first correlation value with the second correlation value; and a timing controller for adjusting the timing of the boundary according to the comparison result.

Brief Description of Drawings

Fig.1 is a schematic diagram of an ISI detector according to one embodiment of the present invention.

Fig.2 is a schematic diagram of an ISI detector according to another embodiment of the present invention.

Fig.3 is a schematic diagram of an ICSI detector according to an embodiment of the present invention.

Detailed Description

Please refer to Fig.1, which is a schematic diagram of an ISI detector 20 according to one embodiment of the present invention. As shown in Fig.1, the ISI detector 20 is coupled to a timing controller 62, and the ISI detector 20 comprises two correlators 21, 41 for respectively generating a correlation value R_{pre} and a correlation value R_{nxt} and a comparator 60 to compare both correlation values. The correlation value R_{pre} represents the magnitude of the ISI caused by the previous symbol, and the correlation value R_{nxt} represents the magnitude of the ISI caused by the next symbol. The comparator 60 is used to compare the correlation value R_{pre} with the correlation value R_{nxt} and generate a control signal Sc according to the comparison result. The timing controller 62 is used to control the timing of a boundary of an OFDM system

according to the control signal Sc.

As shown in Fig.1, the correlator 21 of this embodiment comprises conjugating units 22,……, 32, multipliers 24,……, 34, low-pass filters 25,……, 35, absolute value calculating units 26,……, 36, and a summation unit 28. The conjugating units 22,……, 32 are used for respectively generating conjugated pilot data $P_1(n)^*$,……, $P_k(n)^*$ by conjugating corresponding pilot data $P_1(n)$,……, $P_k(n)$ that was transmitted using the current symbol. The multipliers 24,……, 34 are used for respectively generating product values by multiplying those conjugated pilot data $P_1(n)^*$, $P_k(n)^*$ with a corresponding comparison data $\hat{P}_1(n-1)$,……, $\hat{P}_k(n-1)$ that was transmitted using the previous symbol. The low-pass filters 25,….., 35 are used for averaging the product values outputted from these multipliers 24, 34, respectively. The absolute value calculating units 26,……, 36 are used for generating absolute values of the average values corresponding to the product values. The summation unit 28 is used for generating a correlation value R_{pre} by summing these absolute values.

Similarly, the correlator 41 comprises conjugating units 42,……, 52, multipliers 44,……, 54, low-pass filters 45,……, 55, absolute value calculating units 46,……, 56, and a summation unit 48. The conjugating units 42,……, 52 are used for respectively generating conjugated pilot data $P_1(n)^*$,……, $P_k(n)^*$ by conjugating corresponding pilot data $P_1(n)$, ……, $P_k(n)$ that was transmitted using a current symbol. The multipliers 44,……, 54 are used for respectively generating product values by multiplying those conjugated pilot data $P_1(n)^*$,……, $P_k(n)^*$ with a corresponding comparison data $\hat{P}_1(n+1)$,……, $\hat{P}_k(n+1)$ that was transmitted using the next symbol. The low-pass filters 45,……, 55 are used for averaging the product values outputted from these multipliers 44, ……,54, respectively. The absolute value

calculating units 46,……, 56 are used for generating absolute values of the average values corresponding to the product values outputted from these multipliers 44, ……, 54. The summation unit 48 is used for generating a correlation value R_{nxt} by summing these absolute values.

According to the well-known theorem of correlation, the following Equations (1) and (2) are used to better explain operations of the correlators 21, 41.

$$R_{pre} = \sum_{k=1}^{K} abs(E[\hat{P}_k(n-1) \cdot P_k(n)^*]) \qquad \text{Equation (1)}$$

$$R_{nxt} = \sum_{k=1}^{K} abs(E[\hat{P}_k(n+1) \cdot P_k(n)^*]) \qquad \text{Equation (2)}$$

$P_k(n)^*$ denotes the conjugated pilot data transmitted using an n^{th} symbol via the a k^{th} sub-carrier, $\hat{P}_k(n-1)$ denotes the comparison data transmitted using an $(n-1)^{th}$ symbol via a k^{th} sub-carrier, and $\hat{P}_k(n+1)$ denotes another comparison data transmitted using an $(n+1)^{th}$ symbol via a k^{th} sub-carrier. Please note that the more sub-carriers that are considered, the more reliable result will be generated.

This embodiment of ISI detector is for use in the OFDM system that the pilot of different symbols transmitted via the same sub-carrier have known but different predetermined values. As the result, $\hat{P}_k(n-1)$ and $\hat{P}_k(n+1)$ denote those known predetermined values of pilot in this embodiment. Since the pilots of two different symbols are different, the correlation between pilots of different symbols is due to the interference between these two symbols. Therefore, if the correlation value R_{pre} is greater than the correlation value R_{nxt}, it means that the interference is mainly introduced from using the previous symbol, which is due to the timing of the detected boundary is ahead of that of the ideal boundary. In this manner, the timing controller

62 delays the timing of the boundary according to the control signal Sc outputted from the comparator 60. On the other hand, if the correlation value R_{pre} is less than the correlation value R_{nxt}, it means that the interference is mainly introduced from the following symbol, which is due to the timing of the detected boundary lags behind that of the ideal boundary. In this manner, the comparator 60 outputs the control signal Sc to the timing controller 62 for advancing the timing of the boundary. As a result, the ISI effect is alleviated.

Please refer to Fig.2, which is a schematic diagram of an ISI detector 80 according to another embodiment of the present invention. As show in Fig.2, the ISI detector 80 comprises two correlators 90, 110 and a comparator 120. The correlators 90, 110 are used for generating correlation values R_{pre} and R_{nxt}, respectively. The comparator 120 compares the correlation value R_{pre} with the correlation value R_{nxt} for outputting a control signal Sc to control the timing controller 129.

In this embodiment, the correlator 90 has 1^{st} delay circuits 91a,……, 101a, 2^{nd} delay circuits 91b,……,101b, conjugating units 92,……, 102, multipliers 93,……, 103, equalizers 94a,……, 104a, slicers 94b,……,104b, low-pass filters 95,……, 105, absolute value calculating units 96,……, 106, and a summation unit 98. Concerning the other correlator 110, it has 1^{st} delay circuits 111, ……, 121, conjugating units 112,……, 122, multipliers 113,……, 123, equalizers 114a,……, 124a, slicers 114b,…….,124b, low-pass filters 115,……, 125, absolute value calculating units 116,……, 126, and a summation unit 128. Please note that the components shown in Figs.1 and 2 that have the same name have substantially the same functionality and operation. The related description, therefore, is not repeated for simplicity.

For an OFDM system having pilot transmitted via the same pilot sub-carrier using different symbols corresponding to the same value, the ISI detector 80 is preferably utilized. As shown in Fig.2, the comparison data $\hat{Q}_1(n-1),\ldots\ldots,\hat{Q}_k(n-1)$ are the decision results from received data signals $Q_1(n-1)$,......, $Q_k(n-1)$ through the corresponding equalizers 94a, ...,104a, and the slicers 94b,......,104b, wherein the data signals $Q_1(n-1)$,......, $Q_k(n-1)$ are delayed by the corresponding 1st delay circuits 91a,......,101a, 2nd delay circuits 91b,......,101b and then transmitted to the equalizers 94a,......,104a. Regarding the comparison data signals $\hat{Q}_1(n+1),\ldots\ldots,\hat{Q}_k(n+1)$, they are generated by directly equalizing and slicing the data signals $Q_1(n+1)$,......, $Q_k(n+1)$ with the corresponding equalizers 114a,......, 124a and slicers 94b,......,104b .

It should be noted that the symbol Q(.) represents the received data signal of the corresponding sub-carrier and the symbol $\hat{Q}$ (.) represents the result of equalizing and slicing of the data signal of Q(.).

With the circuit configuration shown in Fig.2, the correlation values R_{pre} and R_{nxt} are computed according to the following equations (3) and (4).

$$R_{pre} = \sum_{k=1}^{K} abs(E[\hat{Q}_k(n-1) \cdot Q_k(n)^*]) \qquad \text{Equation (3)}$$

$$R_{nxt} = \sum_{k=1}^{K} abs(E[\hat{Q}_k(n+1) \cdot Q_k(n)^*]) \qquad \text{Equation (4)}$$

$Q_k(n)^*$ denotes the conjugated data signal transmitted using an n^{th} symbol via the a k^{th} sub-carrier , $\hat{Q}_k(n-1)$ denotes the equalized comparison data signal transmitted using an $(n-1)^{th}$ symbol via a k^{th} sub-carrier, and $\hat{Q}_k(n+1)$ denotes another equalized comparison data signal transmitted using an $(n+1)^{th}$ symbol via a k^{th}

sub-carrier.

Therefore, if the correlation value R_{pre} is greater than the correlation value R_{nxt}, it means that the interference is mainly caused by the previous symbol, in this manner, the timing of the boundary is delayed by the timing controller 114a. If the correlation value R_{pre} is smaller than the correlation value R_{nxt}, it means that the interference is mainly caused by the next symbol, in this manner, the timing is advanced by the timing controller 129. In the end, the ISI effect is alleviated.

It is well-known that the ISI might be introduced by adjacent sub-carriers as well. That is, inter-carrier-symbol-interference (ICSI) occurs. Please refer to Fig.3, which is a schematic diagram of an ICSI detector 160 according to the third embodiment of the present invention. In this embodiment, k sub-carriers of the different symbols for transmitting data are chosen through decision directed method for determining ISI. Since the data of two different sub-carriers are different, the correlation between the data of different sub-carriers is due to the interference between these two sub-carriers.

The ICSI detector 160 has two correlators 130, 150 and a comparator 170. The correlator 130 includes conjugating units 131,……, 141, equalizers 132a, 132b,……, 142a, 142b, slicers 132c,132d……,142c,142d, multipliers 133a, 133b,……, 143a, 143b, low-pass filters 134a, 134b,……, 144a, 144b, absolute value calculating units 136a, 136b,……, 146a, 146b, and a summation unit 138. Similarly, the correlator 150 includes conjugating units 151,……, 161, equalizers 152a, 152b,……, 162a, 162b, slicers 152c,152d,……162c,162d, multipliers 153a, 153b,……, 163a, 163b, low-pass filters 154a, 154b,……, 164a, 164b, absolute value calculating units 156a, 156b,……, 166a, 166b, and a summation unit 158.

I t is obvious that the correlators 130, 150 have substantially the same circuit architecture. However, the data inputted into the correlators 130, 140 are different. Please note that the components shown in Figs.1, 2, and 3 that have the same name have substantially the same functionality and operation. The related description, therefore, is not repeated for simplicity. The following equations (5) and (6) are used to better explain operations of the correlators 130 and 150.

$$R_{pre} = \sum_{k=1}^{K} \left(abs(E[\hat{D}_{k-1}(n-1) \cdot D_k(n)^*]) + abs(E[\hat{D}_{k+1}(n-1) \cdot D_k(n)^*]) \right)$$

Equation (5)

$D_k(n)^*$ represents the conjugate of data $D_k(n)$ transmitted using an n^{th} symbol via a k^{th} sub-carrier, $\hat{D}_{k-1}(n-1)$ denotes a decision result of data $D_{k-1}(n-1)$ transmitted using an $(n-1)^{th}$ symbol via a $(k-1)^{th}$ sub-carrier, and $\hat{D}_{k+1}(n-1)$ denotes a decision result of data $D_{k+1}(n-1)$ transmitted using an $(n-1)^{th}$ symbol via a $(k+1)^{th}$ sub-carrier. As a result, the correlation value R_{pre} is computed to estimate the magnitude of ICSI imposed upon the data $D_k(n)$. That is, the ICSI generated from the adjacent $(k-1)^{th}$ sub-carrier and $(k+1)^{th}$ sub-carrier using a previous symbol is calculated according to the above Equation (5).

$$R_{nxt} = \sum_{k=1}^{K} \left(abs(E[\hat{D}_{k-1}(n+1) \cdot D_k(n)^*]) + abs(E[\hat{D}_{k+1}(n+1) \cdot D_k(n)^*]) \right)$$

Equation (6)

$D_k(n)^*$ represents the conjugate of data $D_k(n)$ transmitted using an n^{th} symbol via a k^{th} sub-carrier, $\hat{D}_{k-1}(n+1)$ denotes a decision result of data $D_{k-1}(n+1)$ transmitted using an $(n+1)^{th}$ symbol via a $(k-1)^{th}$ sub-carrier, and $\hat{D}_{k+1}(n+1)$ denotes a decision

result of data $D_{k+1}(n+1)$ transmitted using an $(n+1)^{th}$ symbol via a $(k+1)^{th}$ sub-carrier. It is clear that the correlation value R_{nxt} is also computed to estimate the magnitude of ICSI imposed upon the data $D_k(n)$. In other words, the ICSI generated from the adjacent $(k-1)^{th}$ sub-carrier and $(k+1)^{th}$ sub-carrier using a following symbol is calculated according to the above Equation (6). Please note that data processed by correlators 130 and 150 are transmitted via data sub-carriers not pilot sub-carriers. Finally, the comparator 170 shown in Fig.3 compares the correlation value R_{pre} with the correlation value R_{nxt} for searching a greater one. If the correlation value R_{pre} is greater than the correlation value R_{nxt}, it means that the interference is mainly caused by the previous symbol, in this manner, the timing of the boundary would be delayed by the timing controller 172. If the correlation value R_{pre} is smaller than the correlation value R_{nxt}, it means that the interference is mainly caused by the next symbol, in this manner, the timing of the boundary of the OFDM system would be advanced by the timing controller 172. Therefore, the ICSI effect is alleviated.

In the above embodiments, please note the absolute values are directly summed to generate the wanted correlation values R_{pre} and R_{nxt}. However, the correlation values R_{pre} and R_{nxt} can be generated by using square values instead of the absolute values. For instance, each of the product values is squared before the summation value is calculated. That is, the above Equations (1)-(6) are replaced with the following equations, respectively.

$$R_{pre} = \sum_{k=1}^{K} (E[\hat{P}_k(n-1) \cdot P_k(n)^*])^2 \qquad \text{Equation (1.1)}$$

$$R_{nxt} = \sum_{k=1}^{K} (E[\hat{P}_k(n+1) \cdot P_k(n)^*])^2 \qquad \text{Equation (2.1)}$$

$$R_{pre} = \sum_{k=1}^{K} (E[\hat{Q}_k(n-1) \cdot Q_k(n)^*])^2 \qquad \text{Equation (3.1)}$$

$$R_{nxt} = \sum_{k=1}^{K} (E[\hat{Q}_k(n+1) \cdot Q_k(n)^*])^2$$ Equation (4.1)

$$R_{pre} = \sum_{k=1}^{K} \left((E[\hat{D}_{k-1}(n-1) \cdot D_k(n)^*])^2 + (E[\hat{D}_{k+1}(n-1) \cdot D_k(n)^*])^2 \right)$$

Equation (5.1)

$$R_{nxt} = \sum_{k=1}^{K} \left((E[\hat{D}_{k-1}(n+1) \cdot D_k(n)^*])^2 + (E[\hat{D}_{k+1}(n+1) \cdot D_k(n)^*])^2 \right)$$

Equation (6.1)

The method and related device disclosed in the embodiments of the present invention for detecting ISI/ICSI in an OFDM system for adjusting a boundary of the OFDM system first computes correlation values to predict the source of the ISI/ICSI and then adjusting the boundary after the source of the ISI/ICSI is determined. Therefore, the performance of tracking the boundary of the OFDM system is greatly improved.

Those skilled in the art will readily observe that numerous modifications and alterations of the device and method may be made while retaining the teachings of the invention. Accordingly, the above disclosure should be construed as limited only by the metes and bounds of the appended claims.

Claims

What is claimed is:

1. A method of detecting inter-carrier-symbol interference (ICSI) of a symbol for adjusting a boundary of the symbol utilized by an OFDM system, wherein each symbol includes a plurality of signals respectively transmitting via a plurality of sub-carriers, the method comprising:

computing a first correlation value representing the correlation between at least

one of first signals of a first symbol and at least one of second signals of a second symbol previous to the first symbol, wherein the at least one first signal is transmitted via a first sub-carrier and the at least one second signal is transmitted via a second sub-carrier adjacent to the first sub-carrier;

computing a second correlation value representing the correlation between the at least one first signal and at least one of third signals of a third symbol next to the first symbol, wherein the at least one first signal is transmitted via the first sub-carrier and the at least one third signal is transmitted via the second sub-carrier;

comparing the first correlation value with the second correlation value; and

adjusting the timing of the boundary according to the comparison result.

2. The method of claim 1, wherein the signals include a plurality of pilot signals and a plurality of data signals.

~~3. The method of claim 2, wherein the corresponding pilot signals of the first, the second, and the third symbols are not the same and the at least one first, second, and third signals are all pilot signals.~~

~~4. The method of claim 2, wherein the at least one first, second, and third signals are all data signals.~~

~~5. The method of claim 4, wherein the corresponding pilot signals of the first, the second, and the third symbols are all the same.~~

~~6~~3. The method of claim 1, wherein the step of computing the first correlation value comprises:

computing a conjugated value of the at least one first signal;

multiplying the conjugated at least one first signal~~s~~ by the corresponding one of

the second signals for generating a product value; and

generating the first correlation value according to the summation of the product value.

~~7~~4. The method of claim ~~6~~3, wherein the first correlation value is generated according to ~~the absolute value of~~ the summation of the absolute value of the product value.

~~8~~5. The method of claim ~~6~~3, wherein the first correlation value is generated according to ~~the square value of~~ the summation of the square value of the product value.

~~9~~6. The method of claim 1, wherein the step of computing the second correlation value comprises:

computing a conjugated value of the at least one first signal;

multiplying the conjugated at least one first signal by the corresponding one of the third signals for generating a product value; and

generating the second correlation value according to the summation of the product value.

~~10~~7. The method of claim ~~9~~6, wherein the second correlation value is generated according to ~~the absolute value of~~ the summation of the absolute value of the product value.

~~11~~8. The method of claim ~~9~~6, wherein the second correlation value is generated according to ~~the square value of~~ the summation of the square value of the product value.

~~12~~9. The method of claim 1, wherein method further comprises:

equalizing and slicing the second symbol for generating the at least one second signal; and

equalizing and slicing the third symbol for generating the at least one third signal.

~~13~~10. An apparatus of detecting inter-carrier-symbol interference (ICSI) of a symbol for adjusting a boundary of the symbol utilized by an OFDM system, wherein each symbol includes a plurality of signals respectively transmitting via a plurality of sub-carriers, the apparatus comprising:

a first correlator for computing a first correlation value representing the correlation between at least one of first signals of a first symbol and at least one of second signals of a second symbol previous to the first symbol, wherein the at least one first signal is transmitted via a first sub-carrier and the at least one second signal is transmitted via a second sub-carrier adjacent to the first sub-carriers;

a second correlator for computing a second correlation value representing the correlation between the at least one first signal and at least one of third signals of a third symbol next to the first symbol, wherein the at least one first signal is transmitted via the first sub-carrier and the at least one third signal is transmitted via the second sub-carrier;

a comparator for comparing the first correlation value with the second correlation value; and

a timing controller for adjusting the timing of the boundary according to the comparison result.

~~14~~11. The apparatus of claim ~~13~~10, wherein the signals include a plurality of pilot signals and a plurality of data signals.

~~15. The apparatus of claim 13, wherein the corresponding pilot signals of the first, the second, and the third symbols are not the same and the at least one first,~~

~~second, and third signals are all pilot signals.~~

~~16. The apparatus of claim 13, wherein the at least one first, second, and third signals are all data signals.~~

~~17. The apparatus of claim 16, wherein the corresponding pilot signals of the first, the second, and the third symbols are the same.~~

~~18~~12. The apparatus of claim ~~12~~11, wherein the first correlator further comprises:

a conjugating unit for computing a conjugated value of the at least one first ~~data~~signal;

a multiplying unit for multiplying the conjugated at least one first ~~data~~ signal by the at least one second ~~data~~ signal for generating a product value; and

a correlation value computer for generating the first correlation value according to the product value.

~~19~~13. The apparatus of claim ~~17~~12, wherein the correlation value computer~~correlation value computer further~~ comprises:

a absolute value calculating unit for calculating the absolute value of each of the product values; and

a summation unit for calculating the sum of the absolute value of the product values.

~~20~~14. The apparatus of claim ~~17~~12, wherein the correlation value computer~~correlation value computer further~~ comprises:

a square value calculating unit for calculating the square value of each of the product values; and

a summation unit for calculating the sum of the square value of the product values.

~~21~~15. The apparatus of claim ~~13~~10, wherein the second correlator further

comprises:

a conjugating unit for computing a conjugated value of the at least one first ~~data~~signal;

a multiplying unit for multiplying the conjugated at least one first ~~data~~ signal by the at least one third ~~data~~ signal for generating a product value; and

a correlation value computer for generating the second correlation value according to the product value.

~~22~~16. The apparatus of claim ~~21~~15, wherein the correlation value computer ~~further~~ comprises:

a absolute value calculating unit for calculating the absolute value of each of the product values; and

a summation unit for calculating the sum of the absolute value of the product values.

~~23~~17. The apparatus of claim ~~21~~15, wherein the correlation value computer ~~further~~ comprises:

a square value calculating unit for calculating the square value of each of the product values; and

a summation unit for calculating the sum of the square value of the product values.

~~24~~18. The apparatus of claim ~~13~~10, wherein the apparatus further comprises:

a first equalizer for equalizing the second symbol;

a first slicer coupled to the first correlator for slicing the equalized second symbol and generating the at least one second signal;

a second equalizer for equalizing the third symbol; and

a second slicer coupled to the second correlator for slicing the equalized ~~second~~

third symbol and generating the at least one third signal;

Abstract of Disclosure

A method for detecting inter-carrier-symbol interference (ICSI) in an OFDM system includes the steps of computing a first correlation value representing the correlation between at least one of first signals of a first symbol and at least one of second signals of a second symbol previous to the first symbol, wherein the at least one first signal is transmitted via a first sub-carrier and the at least one second signal is transmitted via a second sub-carrier adjacent to the first sub-carrier; computing a second correlation value representing the correlation between the at least one first signal and at least one of third signals of a third symbol next to the first symbol, wherein the at least one first signal is transmitted via the first sub-carrier and the at least one third signal is transmitted via the second sub-carrier; comparing the first correlation value with the second correlation value; and adjusting the timing of the boundary according to the comparison result.

Figures

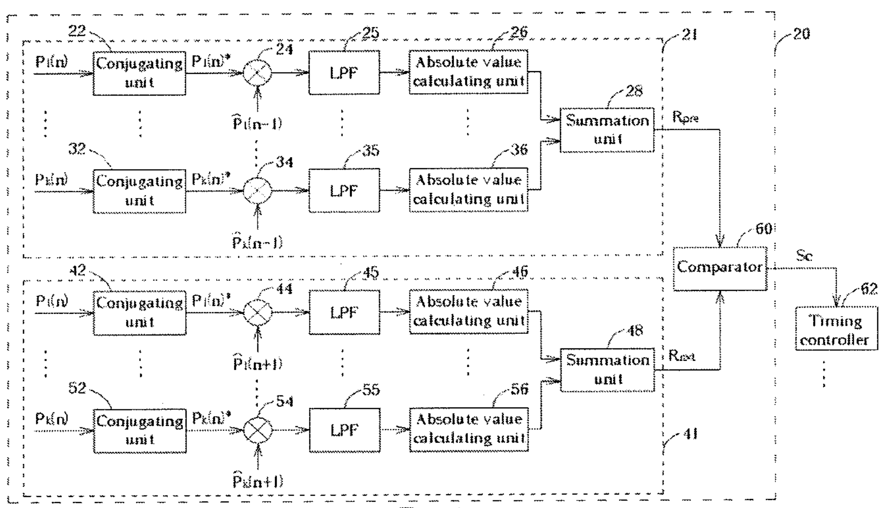

Fig. 1

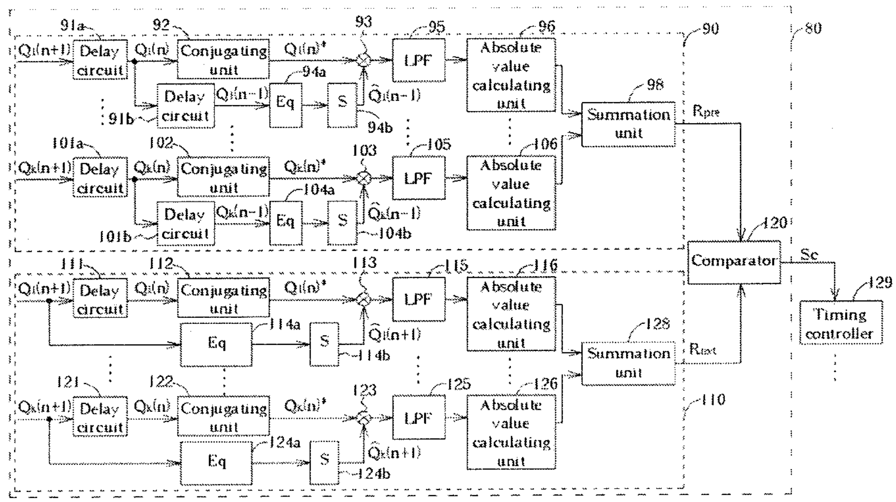
Delay circuit
Conjugating unit
LPF
Absolute value calculating unit
Summation unit
Eq
S
Comparator
Timing controller
R_{pre}
R_{ext}
Sc

Fig. 2

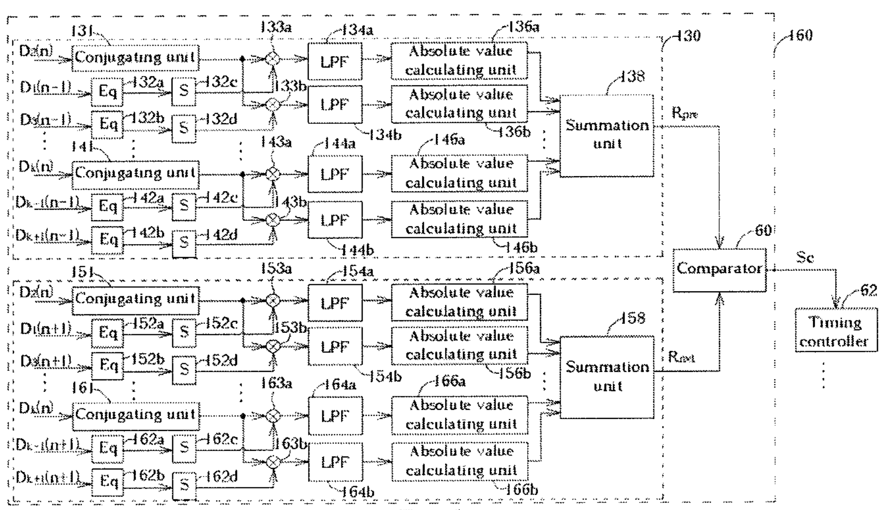
Conjugating unit
Eq
S
LPF
Absolute value calculating unit
Summation unit
Comparator
Timing controller
R_{pre}
R_{ext}
Sc

Fig. 3

Exhibit K

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Best regards,

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Fax: 8923-7390

Email: candicekao@naipo.com.tw(See attached file: REAP0132USA0.DOC)

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Title

METHOD AND APPARATUS OF DETECTING ISI/ICSI IN AN OFDM SYSTEM

Cross Reference To Related Applications

This is a co-pending Application No. XX/XXXXXX, filed on the same day with the present patent application, entitled "METHOD AND APPARATUS OF DETECTING ISI/ICSI IN AN OFDM SYSTEM" and assigned to the same assignee, the contents of which are incorporated herein by reference.

Background of Invention

1. Field of the Invention

The invention relates to an apparatus for use in an OFDM system and a method thereof , and more particularly, to an apparatus for detecting ISI/ICSI in an OFDM system and a method thereof.

2. Description of the Prior Art

Most OFDM transceivers suffer from well-known problems of inter-symbol interference (ISI) and inter-carrier interference (ICI). An additional guard interval (GI) is added between two symbols to recover the ISI and the ICI. When receiving a packet including a plurality of symbols, a conventional OFDM receiver detects the boundary of each symbol, removes GI of each symbol according to the detected boundary of the symbol, and then demodulated the symbol through Fast Fourier Transform (FFT) operation. ~~If~~However the detected boundary may not be reliable owing to the influence of multi-path and other factors.

One conventional art applied to improve the precision of boundary detection is to estimate the time shift of the detected boundary according to the frequency domain linear phase shift of the demodulated data. Another conventional art disclosed is to estimate the time shift of the detected boundary according to the channel impulse response of the symbol. However, when the delay spread phenomenon is too severe, the ISI and ICI problem cannot be recovered by both of the two conventional techniques and the boundary detection may be imprecise which may cause divergence or even failure in receiving when receiving symbols.

Summary of Invention

It is therefore an objective of the claimed invention to provide a method and

apparatus of detecting ISI/ICSI in an OFDM system to solve the above-mentioned problem.

According to the claimed invention, a method of detecting inter-carrier-symbol interference (ICSI) of a symbol for adjusting a boundary of the symbol utilized by an OFDM system is disclosed, wherein each symbol includes a plurality of signals respectively transmitting via a plurality of sub-carriers, the method comprising: computing a first correlation value representing the correlation between at least one of first signals of a first symbol and at least one of second signals of a second symbol previous to the first symbol, wherein the at least one first signal is transmitted via a first sub-carrier and the at least one second signal is transmitted via a second sub-carrier adjacent to the first sub-carrier; computing a second correlation value representing the correlation between the at least one first signal and at least one of third signals of a third symbol next to the first symbol, wherein the at least one first signal is transmitted via the first sub-carrier and the at least one third signal is transmitted via the second sub-carrier; comparing the first correlation value with the second correlation value; and adjusting the timing of the boundary according to the comparison result.

According to the claimed invention, an apparatus of detecting inter-carrier-symbol interference (ICSI) of a symbol for adjusting a boundary of the symbol utilized by an OFDM system is disclosed, wherein each symbol includes a plurality of signals respectively transmitting via a plurality of sub-carriers, the apparatus comprising: a first correlator for computing a first correlation value representing the correlation between at least one of first signals of a first symbol and at least one of second signals of a second symbol previous to the first symbol, wherein the at least one first signal is transmitted via a first sub-carrier and the at least one second signal is transmitted via a second sub-carrier adjacent to the first sub-carriers;

a second correlator for computing a second correlation value representing the correlation between the at least one first signal and at least one of third signals of a third symbol next to the first symbol, wherein the at least one first signal is transmitted via the first sub-carrier and the at least one third signal is transmitted via the second sub-carrier; a comparator for comparing the first correlation value with the second correlation value; and a timing controller for adjusting the timing of the boundary according to the comparison result.

Brief Description of Drawings

Fig.1 is a schematic diagram of an ISI detector according to one embodiment of the present invention.

Fig.2 is a schematic diagram of an ISI detector according to another embodiment of the present invention.

Fig.3 is a schematic diagram of an ICSI detector according to an embodiment of the present invention.

Detailed Description

Please refer to Fig.1, which is a schematic diagram of an ISI detector 20 according to one embodiment of the present invention. As shown in Fig.1, the ISI detector 20 is coupled to a timing controller 62, and the ISI detector 20 comprises two correlators 21, 41 for respectively generating a correlation value R_{pre} and a correlation value R_{nxt} and a comparator 60 to compare both correlation values. The correlation value R_{pre} represents the magnitude of the ISI caused by the previous symbol, and the correlation value R_{nxt} represents the magnitude of the ISI caused by the next symbol. The comparator 60 is used to compare the correlation value R_{pre} with the correlation value R_{nxt} and generate a control signal Sc according to the comparison result. The timing controller 62 is used to control the timing of a boundary of an OFDM system

according to the control signal Sc.

As shown in Fig.1, the correlator 21 of this embodiment comprises conjugating units 22,……, 32, multipliers 24,……, 34, low-pass filters 25,……, 35, absolute value calculating units 26,……, 36, and a summation unit 28. The conjugating units 22,……, 32 are used for respectively generating conjugated pilot data $P_1(n)^*$,……, $P_k(n)^*$ by conjugating corresponding pilot data $P_1(n)$,……, $P_k(n)$ that was transmitted using the current symbol. The multipliers 24,……, 34 are used for respectively generating product values by multiplying those conjugated pilot data $P_1(n)^*$, $P_k(n)^*$ with a corresponding comparison data $\hat{P}_1(n-1)$,……, $\hat{P}_k(n-1)$ that was transmitted using the previous symbol. The low-pass filters 25,….., 35 are used for averaging the product values outputted from these multipliers 24, 34, respectively. The absolute value calculating units 26,……, 36 are used for generating absolute values of the average values corresponding to the product values. The summation unit 28 is used for generating a correlation value R_{pre} by summing these absolute values.

Similarly, the correlator 41 comprises conjugating units 42,……, 52, multipliers 44,……, 54, low-pass filters 45,……, 55, absolute value calculating units 46,……, 56, and a summation unit 48. The conjugating units 42,……, 52 are used for respectively generating conjugated pilot data $P_1(n)^*$,……, $P_k(n)^*$ by conjugating corresponding pilot data $P_1(n)$, ……, $P_k(n)$ that was transmitted using a current symbol. The multipliers 44,……, 54 are used for respectively generating product values by multiplying those conjugated pilot data $P_1(n)^*$,……, $P_k(n)^*$ with a corresponding comparison data $\hat{P}_1(n+1)$,……, $\hat{P}_k(n+1)$ that was transmitted using the next symbol. The low-pass filters 45,……, 55 are used for averaging the product values outputted from these multipliers 44, ……,54, respectively. The absolute value

calculating units 46,......, 56 are used for generating absolute values of the average values corresponding to the product values outputted from these multipliers 44, ..., 54. The summation unit 48 is used for generating a correlation value R_{nxt} by summing these absolute values.

According to the well-known theorem of correlation, the following Equations (1) and (2) are used to better explain operations of the correlators 21, 41.

$$R_{pre} = \sum_{k=1}^{K} abs(E[\hat{P}_k(n-1) \cdot P_k(n)^*]) \qquad \text{Equation (1)}$$

$$R_{nxt} = \sum_{k=1}^{K} abs(E[\hat{P}_k(n+1) \cdot P_k(n)^*]) \qquad \text{Equation (2)}$$

$P_k(n)^*$ denotes the conjugated pilot data transmitted using an n^{th} symbol via the a k^{th} sub-carrier, $\hat{P}_k(n-1)$ denotes the comparison data transmitted using an $(n-1)^{th}$ symbol via a k^{th} sub-carrier, and $\hat{P}_k(n+1)$ denotes another comparison data transmitted using an $(n+1)^{th}$ symbol via a k^{th} sub-carrier. Please note that the more sub-carriers that are considered, the more reliable result will be generated.

This embodiment of ISI detector is for use in the OFDM system that the pilot of different symbols transmitted via the same sub-carrier have known but different predetermined values. As the result, $\hat{P}_k(n-1)$ and $\hat{P}_k(n+1)$ denote those known predetermined values of pilot in this embodiment. Since the pilots of two different symbols are different, the correlation between pilots of different symbols is due to the interference between these two symbols. Therefore, if the correlation value R_{pre} is greater than the correlation value R_{nxt}, it means that the interference is mainly introduced from using the previous symbol, which is due to the timing of the detected boundary is ahead of that of the ideal boundary. In this manner, the timing controller

62 delays the timing of the boundary according to the control signal Sc outputted from the comparator 60. On the other hand, if the correlation value R_{pre} is less than the correlation value R_{nxt}, it means that the interference is mainly introduced from the following symbol, which is due to the timing of the detected boundary lags behind that of the ideal boundary. In this manner, the comparator 60 outputs the control signal Sc to the timing controller 62 for advancing the timing of the boundary. As a result, the ISI effect is alleviated.

Please refer to Fig.2, which is a schematic diagram of an ISI detector 80 according to another embodiment of the present invention. As show in Fig.2, the ISI detector 80 comprises two correlators 90, 110 and a comparator 120. The correlators 90, 110 are used for generating correlation values R_{pre} and R_{nxt}, respectively. The comparator 120 compares the correlation value R_{pre} with the correlation value R_{nxt} for outputting a control signal Sc to control the timing controller 129.

In this embodiment, the correlator 90 has 1st delay circuits 91a,……, 101a, 2nd delay circuits 91b,……,101b, conjugating units 92,……, 102, multipliers 93,……, 103, equalizers 94a,……, 104a, slicers 94b,……,104b, low-pass filters 95,……, 105, absolute value calculating units 96,……, 106, and a summation unit 98. Concerning the other correlator 110, it has 1st delay circuits 111, ……, 121, conjugating units 112,……, 122, multipliers 113,……, 123, equalizers 114a,……, 124a, slicers 114b,…….,124b, low-pass filters 115,……, 125, absolute value calculating units 116,……, 126, and a summation unit 128. Please note that the components shown in Figs.1 and 2 that have the same name have substantially the same functionality and operation. The related description, therefore, is not repeated for simplicity.

For an OFDM system having pilot transmitted via the same pilot sub-carrier using different symbols corresponding to the same value, the ISI detector 80 is preferably utilized. As shown in Fig.2, the comparison data $\hat{Q}_1(n-1)$,......,$\hat{Q}_k(n-1)$ are the decision results from received data signals Q_1(n-1) ,......, Q_k(n-1) through the corresponding equalizers 94a, ...,104a, and the slicers 94b,......,104b, wherein the data signals Q_1(n-1),......, Q_k(n-1) are delayed by the corresponding 1st delay circuits 91a,......,101a, 2nd delay circuits 91b,......,101b and then transmitted to the equalizers 94a,......,104a. Regarding the comparison data signals $\hat{Q}_1(n+1)$,......,$\hat{Q}_k(n+1)$, they are generated by directly equalizing and slicing the data signals Q_1(n+1) ,......, Q_k(n+1) with the corresponding equalizers 114a,......, 124a and slicers 94b,......,104b .

It should be noted that the symbol Q(.) represents the received data signal of the corresponding sub-carrier and the symbol $\hat{Q}$ (.) represents the result of equalizing and slicing of the data signal of Q(.).

With the circuit configuration shown in Fig.2, the correlation values R_{pre} and R_{nxt} are computed according to the following equations (3) and (4).

$$R_{pre} = \sum_{k=1}^{K} abs(E[\hat{Q}_k(n-1) \cdot Q_k(n)^*]) \qquad \text{Equation (3)}$$

$$R_{nxt} = \sum_{k=1}^{K} abs(E[\hat{Q}_k(n+1) \cdot Q_k(n)^*]) \qquad \text{Equation (4)}$$

$Q_k(n)^*$ denotes the conjugated data signal transmitted using an n^{th} symbol via the a k^{th} sub-carrier , $\hat{Q}_k(n-1)$ denotes the equalized comparison data signal transmitted using an $(n-1)^{th}$ symbol via a k^{th} sub-carrier, and $\hat{Q}_k(n+1)$ denotes another equalized comparison data signal transmitted using an $(n+1)^{th}$ symbol via a k^{th}

sub-carrier.

Therefore, if the correlation value R_{pre} is greater than the correlation value R_{nxt}, it means that the interference is mainly caused by the previous symbol, in this manner, the timing of the boundary is delayed by the timing controller 114a. If the correlation value R_{pre} is smaller than the correlation value R_{nxt}, it means that the interference is mainly caused by the next symbol, in this manner, the timing is advanced by the timing controller 129. In the end, the ISI effect is alleviated.

It is well-known that the ISI might be introduced by adjacent sub-carriers as well. That is, inter-carrier-symbol-interference (ICSI) occurs. Please refer to Fig.3, which is a schematic diagram of an ICSI detector 160 according to the third embodiment of the present invention. In this embodiment, k sub-carriers of the different symbols for transmitting data are chosen through decision directed method for determining ISI. Since the data of two different sub-carriers are different, the correlation between the data of different sub-carriers is due to the interference between these two sub-carriers.

The ICSI detector 160 has two correlators 130, 150 and a comparator 170. The correlator 130 includes conjugating units 131,......, 141, equalizers 132a, 132b,......, 142a, 142b, slicers 132c,132d......,142c,142d, multipliers 133a, 133b,......, 143a, 143b, low-pass filters 134a, 134b,......, 144a, 144b, absolute value calculating units 136a, 136b,......, 146a, 146b, and a summation unit 138. Similarly, the correlator 150 includes conjugating units 151,......, 161, equalizers 152a, 152b,......, 162a, 162b, slicers 152c,152d,......162c,162d, multipliers 153a, 153b,......, 163a, 163b, low-pass filters 154a, 154b,......, 164a, 164b, absolute value calculating units 156a, 156b,......, 166a, 166b, and a summation unit 158.

I t is obvious that the correlators 130, 150 have substantially the same circuit architecture. However, the data inputted into the correlators 130, 140 are different. Please note that the components shown in Figs.1, 2, and 3 that have the same name have substantially the same functionality and operation. The related description, therefore, is not repeated for simplicity. The following equations (5) and (6) are used to better explain operations of the correlators 130 and 150.

$$R_{pre} = \sum_{k=1}^{K}\left(abs(E[\hat{D}_{k-1}(n-1)\cdot D_k(n)^*]) + abs(E[\hat{D}_{k+1}(n-1)\cdot D_k(n)^*])\right)$$

Equation (5)

$D_k(n)^*$ represents the conjugate of data $D_k(n)$ transmitted using an n^{th} symbol via a k^{th} sub-carrier, $\hat{D}_{k-1}(n-1)$ denotes a decision result of data $D_{k-1}(n-1)$ transmitted using an $(n-1)^{th}$ symbol via a $(k-1)^{th}$ sub-carrier, and $\hat{D}_{k+1}(n-1)$ denotes a decision result of data $D_{k+1}(n-1)$ transmitted using an $(n-1)^{th}$ symbol via a $(k+1)^{th}$ sub-carrier. As a result, the correlation value R_{pre} is computed to estimate the magnitude of ICSI imposed upon the data $D_k(n)$. That is, the ICSI generated from the adjacent $(k-1)^{th}$ sub-carrier and $(k+1)^{th}$ sub-carrier using a previous symbol is calculated according to the above Equation (5).

$$R_{nxt} = \sum_{k=1}^{K}\left(abs(E[\hat{D}_{k-1}(n+1)\cdot D_k(n)^*]) + abs(E[\hat{D}_{k+1}(n+1)\cdot D_k(n)^*])\right)$$

Equation (6)

$D_k(n)^*$ represents the conjugate of data $D_k(n)$ transmitted using an n^{th} symbol via a k^{th} sub-carrier, $\hat{D}_{k-1}(n+1)$ denotes a decision result of data $D_{k-1}(n+1)$ transmitted using an $(n+1)^{th}$ symbol via a $(k-1)^{th}$ sub-carrier, and $\hat{D}_{k+1}(n+1)$ denotes a decision

result of data $D_{k+1}(n+1)$ transmitted using an $(n+1)^{th}$ symbol via a $(k+1)^{th}$ sub-carrier. It is clear that the correlation value R_{nxt} is also computed to estimate the magnitude of ICSI imposed upon the data $D_k(n)$. In other words, the ICSI generated from the adjacent $(k-1)^{th}$ sub-carrier and $(k+1)^{th}$ sub-carrier using a following symbol is calculated according to the above Equation (6). Please note that data processed by correlators 130 and 150 are transmitted via data sub-carriers not pilot sub-carriers. Finally, the comparator 170 shown in Fig.3 compares the correlation value R_{pre} with the correlation value R_{nxt} for searching a greater one. If the correlation value R_{pre} is greater than the correlation value R_{nxt}, it means that the interference is mainly caused by the previous symbol, in this manner, the timing of the boundary would be delayed by the timing controller 172. If the correlation value R_{pre} is smaller than the correlation value R_{nxt}, it means that the interference is mainly caused by the next symbol, in this manner, the timing of the boundary of the OFDM system would be advanced by the timing controller 172. Therefore, the ICSI effect is alleviated.

In the above embodiments, please note the absolute values are directly summed to generate the wanted correlation values R_{pre} and R_{nxt}. However, the correlation values R_{pre} and R_{nxt} can be generated by using square values instead of the absolute values. For instance, each of the product values is squared before the summation value is calculated. That is, the above Equations (1)-(6) are replaced with the following equations, respectively.

$$R_{pre} = \sum_{k=1}^{K} (E[\hat{P}_k(n-1) \cdot P_k(n)^*])^2 \qquad \text{Equation (1.1)}$$

$$R_{nxt} = \sum_{k=1}^{K} (E[\hat{P}_k(n+1) \cdot P_k(n)^*])^2 \qquad \text{Equation (2.1)}$$

$$R_{pre} = \sum_{k=1}^{K} (E[\hat{Q}_k(n-1) \cdot Q_k(n)^*])^2 \qquad \text{Equation (3.1)}$$

$$R_{nxt} = \sum_{k=1}^{K} (E[\hat{Q}_k(n+1) \cdot Q_k(n)^*])^2$$ Equation (4.1)

$$R_{pre} = \sum_{k=1}^{K} \left((E[\hat{D}_{k-1}(n-1) \cdot D_k(n)^*])^2 + (E[\hat{D}_{k+1}(n-1) \cdot D_k(n)^*])^2 \right)$$

Equation (5.1)

$$R_{nxt} = \sum_{k=1}^{K} \left((E[\hat{D}_{k-1}(n+1) \cdot D_k(n)^*])^2 + (E[\hat{D}_{k+1}(n+1) \cdot D_k(n)^*])^2 \right)$$

Equation (6.1)

The method and related device disclosed in the embodiments of the present invention for detecting ISI/ICSI in an OFDM system for adjusting a boundary of the OFDM system first computes correlation values to predict the source of the ISI/ICSI and then adjusting the boundary after the source of the ISI/ICSI is determined. Therefore, the performance of tracking the boundary of the OFDM system is greatly improved.

Those skilled in the art will readily observe that numerous modifications and alterations of the device and method may be made while retaining the teachings of the invention. Accordingly, the above disclosure should be construed as limited only by the metes and bounds of the appended claims.

Claims

What is claimed is:

1. A method of detecting inter-carrier-symbol interference (ICSI) of a symbol for adjusting a boundary of the symbol utilized by an OFDM system, wherein each symbol includes a plurality of signals respectively transmitting via a plurality of sub-carriers, the method comprising:

computing a first correlation value representing the correlation between at least

one of first signals of a first symbol and at least one of second signals of a second symbol previous to the first symbol, wherein the at least one first signal is transmitted via a first sub-carrier and the at least one second signal is transmitted via a second sub-carrier adjacent to the first sub-carrier;

computing a second correlation value representing the correlation between the at least one first signal and at least one of third signals of a third symbol next to the first symbol, wherein the at least one first signal is transmitted via the first sub-carrier and the at least one third signal is transmitted via the second sub-carrier;

comparing the first correlation value with the second correlation value; and

adjusting the timing of the boundary according to the comparison result.

2. The method of claim 1, wherein the signals include a plurality of pilot signals and a plurality of data signals.

~~3. The method of claim 2, wherein the corresponding pilot signals of the first, the second, and the third symbols are not the same and the at least one first, second, and third signals are all pilot signals.~~

~~4. The method of claim 2, wherein the at least one first, second, and third signals are all data signals.~~

~~5. The method of claim 4, wherein the corresponding pilot signals of the first, the second, and the third symbols are all the same.~~

~~6~~3. The method of claim 1, wherein the step of computing the first correlation value comprises:

computing a conjugated value of the at least one first signal;

multiplying the conjugated at least one first signals by the corresponding one of

the second signals for generating a product value; and

generating the first correlation value according to the summation of the product value.

~~7~~4. The method of claim ~~6~~3, wherein the first correlation value is generated according to ~~the absolute value of~~ the summation of the absolute value of the product value.

~~8~~5. The method of claim ~~6~~3, wherein the first correlation value is generated according to ~~the square value of~~ the summation of the square value of the product value.

~~9~~6. The method of claim 1, wherein the step of computing the second correlation value comprises:

computing a conjugated value of the at least one first signal;

multiplying the conjugated at least one first signal by the corresponding one of the third signals for generating a product value; and

generating the second correlation value according to the summation of the product value.

~~10~~7. The method of claim ~~9~~6, wherein the second correlation value is generated according to ~~the absolute value of~~ the summation of the absolute value of the product value.

~~11~~8. The method of claim ~~9~~6, wherein the second correlation value is generated according to ~~the square value of~~ the summation of the square value of the product value.

~~12~~9. The method of claim 1, wherein method further comprises:

equalizing and slicing the second symbol for generating the at least one second signal; and

equalizing and slicing the third symbol for generating the at least one third signal.

~~13~~10. An apparatus of detecting inter-carrier-symbol interference (ICSI) of a symbol for adjusting a boundary of the symbol utilized by an OFDM system, wherein each symbol includes a plurality of signals respectively transmitting via a plurality of sub-carriers, the apparatus comprising:

a first correlator for computing a first correlation value representing the correlation between at least one of first signals of a first symbol and at least one of second signals of a second symbol previous to the first symbol, wherein the at least one first signal is transmitted via a first sub-carrier and the at least one second signal is transmitted via a second sub-carrier adjacent to the first sub-carriers;

a second correlator for computing a second correlation value representing the correlation between the at least one first signal and at least one of third signals of a third symbol next to the first symbol, wherein the at least one first signal is transmitted via the first sub-carrier and the at least one third signal is transmitted via the second sub-carrier;

a comparator for comparing the first correlation value with the second correlation value; and

a timing controller for adjusting the timing of the boundary according to the comparison result.

~~14~~11. The apparatus of claim ~~13~~10, wherein the signals include a plurality of pilot signals and a plurality of data signals.

~~15. The apparatus of claim 13, wherein the corresponding pilot signals of the first, the second, and the third symbols are not the same and the at least one first,~~

~~second, and third signals are all pilot signals.~~

~~16. The apparatus of claim 13, wherein the at least one first, second, and third signals are all data signals.~~

~~17. The apparatus of claim 16, wherein the corresponding pilot signals of the first, the second, and the third symbols are the same.~~

~~18~~12. The apparatus of claim ~~12~~11, wherein the first correlator further comprises:

a conjugating unit for computing a conjugated value of the at least one first ~~data~~signal;

a multiplying unit for multiplying the conjugated at least one first ~~data~~ signal by the at least one second ~~data~~ signal for generating a product value; and

a correlation value computer for generating the first correlation value according to the product value.

~~19~~13. The apparatus of claim ~~17~~12, wherein the correlation value computer~~correlation value computer further~~ comprises:

a absolute value calculating unit for calculating the absolute value of each of the product values; and

a summation unit for calculating the sum of the absolute value of the product values.

~~20~~14. The apparatus of claim ~~17~~12, wherein the correlation value computer~~correlation value computer further~~ comprises:

a square value calculating unit for calculating the square value of each of the product values; and

a summation unit for calculating the sum of the square value of the product values.

~~21~~15. The apparatus of claim ~~13~~10, wherein the second correlator further

comprises:

a conjugating unit for computing a conjugated value of the at least one first ~~data~~signal;

a multiplying unit for multiplying the conjugated at least one first ~~data~~ signal by the at least one third ~~data~~ signal for generating a product value; and

a correlation value computer for generating the second correlation value according to the product value.

~~22~~16. The apparatus of claim ~~21~~15, wherein the correlation value computer ~~further~~ comprises:

a absolute value calculating unit for calculating the absolute value of each of the product values; and

a summation unit for calculating the sum of the absolute value of the product values.

~~23~~17. The apparatus of claim ~~21~~15, wherein the correlation value computer ~~further~~ comprises:

a square value calculating unit for calculating the square value of each of the product values; and

a summation unit for calculating the sum of the square value of the product values.

~~24~~18. The apparatus of claim ~~13~~10, wherein the apparatus further comprises:

a first equalizer for equalizing the second symbol;

a first slicer coupled to the first correlator for slicing the equalized second symbol and generating the at least one second signal;

a second equalizer for equalizing the third symbol; and

a second slicer coupled to the second correlator for slicing the equalized ~~second~~

third symbol and generating the at least one third signal;

Abstract of Disclosure

A method for detecting inter-carrier-symbol interference (ICSI) in an OFDM system includes the steps of computing a first correlation value representing the correlation between at least one of first signals of a first symbol and at least one of second signals of a second symbol previous to the first symbol, wherein the at least one first signal is transmitted via a first sub-carrier and the at least one second signal is transmitted via a second sub-carrier adjacent to the first sub-carrier; computing a second correlation value representing the correlation between the at least one first signal and at least one of third signals of a third symbol next to the first symbol, wherein the at least one first signal is transmitted via the first sub-carrier and the at least one third signal is transmitted via the second sub-carrier; comparing the first correlation value with the second correlation value; and adjusting the timing of the boundary according to the comparison result.

Figures

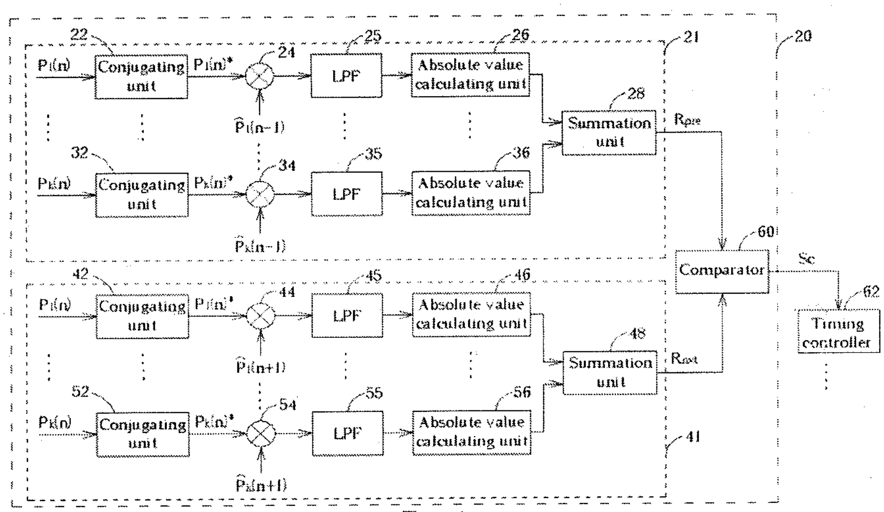

Fig. 1

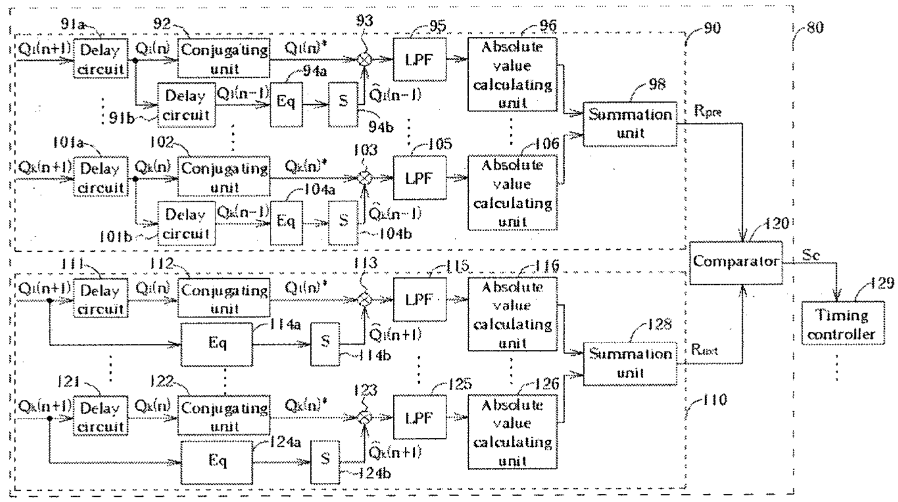
Delay circuit
Conjugating unit
Eq
S
LPF
Absolute value calculating unit
Summation unit
Comparator
Timing controller
Rpre
Rnxt
Sc

Fig. 2

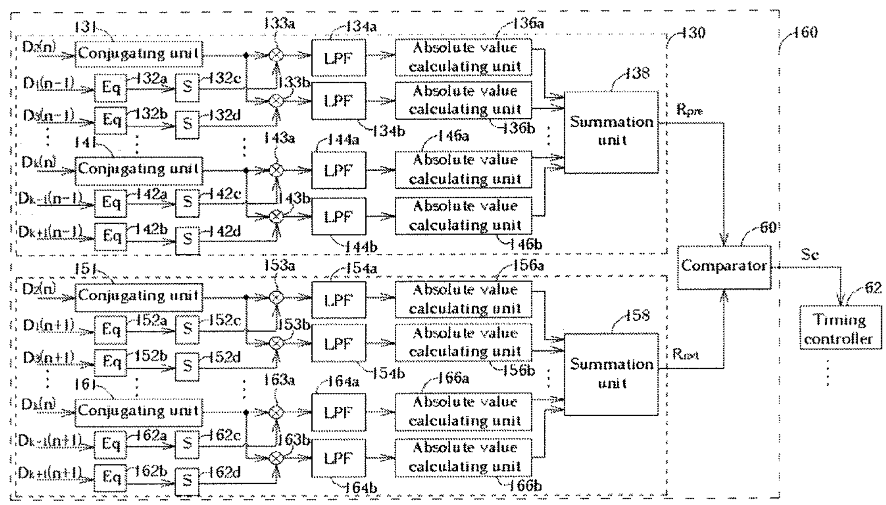
Conjugating unit
Eq
S
LPF
Absolute value calculating unit
Summation unit
Comparator
Timing controller
Rpre
Rnxt
Sc

Fig. 3